HURRICANE HEAT POTENTIAL OF THE NORTH ATLANTIC AND NORTH PACIFIC OCEANS

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THESIS

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by

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ABSTRACT

Mean monthly ocean temperature data provided by Fleet Numerical Weather Central were used as a basis for computation of a quantity defined as hurricane heat potential. Warm, deep centers with heat potential values in excess of 32,000 cal/cm^2 existed east of the Philippine Islands during the months of July through November. In the Western Atlantic warm, deep centers in excess of 24,000 cal/cm^2 existed south of Cuba during the months of August through October. Correlation studies were made between sea surface temperature and heat potential. A weak correlation was found, leading to the conclusion that sea surface temperature at least at times is a poor indicator of oceanic heat content. Computations were made to determine the effect of average heat less during a severe tropical storm passage to the ocean thermal structure. Twenty-four hour average losses would cause the sea surface temperature to drop as much as three degrees celsius under certain initial conditions. The effects of heat loss on convective layer depth ranged from less than fifteen meters to over ninety meters.

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DEFINITIONS

The following key terms and their definitions are used throughout this thesis:

Hurricane Heat Potential - Excess ocean heat content over that contained in 26°C water (Whitaker, 1967)

Layer Depth - Taken as the depth at which the temperature differential from the surface is 1.12°C (2°F).

Sea Surface Temperature Modification - The temperature decrease at the sea surface due to heat loss during the passage of a severe tropical storm.

Convective Layer Depth - Depth of severe tropical storm influence to thermal structure due to convective and mechanical mixing.

Depth of 26C Isotherm - Depth below which no heat potential exists. (The assumed maximum depth of severe tropical storm influence on the thermal structure due to heat loss).

Excess Temperature - The increment of temperature above 26°C.

Hurricane - A major storm in the Atlantic with winds greater than 64 knots.

Typhoon - A major storm in the Pacific with winds greater than 64 knots.

Tropical Storm - A major storm with winds greater than 34 knots.

Severe Tropical Storm - A hurricane or typhoon.

I. INTRODUCTION

A. REVIEW OF THE LITERATURE

The tropical storm problem has consumed much time and effort in the environmental sciences yet a completely satisfactory understanding remains to be achieved.

It has been known for some time that tropical storms derive energy from the ocean over which they travel. Leipper and Volgenau (1972) summarized investigations of the relationships between sea surface temperature and severe tropical storms. These investigations indicated that severe tropical storms intensified over warm water and dissipated over cool water. In a specific study Perlroth (1967) stated that use of sea surface temperature as the sole oceanic criterion for use in tropical storm studies was not sufficient but that knowledge of the ocean's vertical temperature profile was essential in determining the available energy. Perlroth used the difference between sea surface temperature and the temperature at 200 feet in the Equatorial Atlantic to indicate mean "potentials" in the ocean for the intensification of tropical storms to hurricanes. He analyzed all hurricanes during the period 1901-1965 and found that approximately 90% had their origin over areas where the average (64 year) vertical temperature difference between the surface and 200 feet was 3.9°C or less and that only 4% had their inception when the gradient was greater than 8.4°C. Of course, other factors may be involved in explaining this indicated relationship.

Although Perlroth cautions forecasters on relying too heavily on sea surface temperature data, it usually is a good indicator for use in tropical storm studies. Severe tropical storms do not form over areas where the sea surface temperature is less than 26C (BYERS, 1959).

Using the 26C reference Leipper and Volgenau (1972) studied the hurricane heat potential of the Gulf of Mexico during the month of August for the individual years 1965 to 1968 when unusual pre-hurricane season oceanic data were available. They found that the hurricane heat potential varied from approximately 700 to 31,600 calories/cm^2 column. The areas of high heat potential were found to vary yearly. Computations showed that a passing hurricane with an assumed flux from the sea of 4,000 cal/cm^2/day would cause the sea surface temperature to decrease .8°C to 3.1°C per day, depending on the initial temperature structure in the region considered.

The approximate figure of 4,000 cal/cm^2/day average heat loss from the ocean during passage of a typical hurricane is indicated by the work of Malkus and Riehl (1960) who used a value of 3,140 cal/cm^2/ day; and by Whitaker (1967) whose calculations for hurricane Betsy were 3,750 cal/cm^2/day. Since the sensible and latent heat transfer formulas are linearly dependent on wind speed, the 4,000 cal/cm^2/day value would be increased or decreased to fit the "non-typical" storms. However, use of the rough figure of 4,000 gives a good approximation and enables calculations to be made of hurricane effect on sea surface temperature and convective layer depth.

Other researchers who employed the hurricane heat potential concept were Leipper and Jensen (1971). They calculated the sea surface temperature changes during passage of a hurricane using the same base data and

average heat consumption criterion as Volgenau. Jensen's computations indicated sea surface temperature decreases sometimes less than one degree and sometimes more than four degrees celsius after a twenty-four hour period depending upon initial ocean temperature structure. He found that, in general, areas of high concentrations of heat had smaller decreases of sea surface temperature with a given heat loss. Computed and observed post-hurricane sea surface temperatures were compared and a fair correlation was found. Jensen considered the computed values to be more representative of actual conditions immediately after passage of a hurricane than the observed values since advective processes probably distorted the observed values taken at some later date.

B. OBJECTIVE

This thesis has two primary objectives, the first is to produce a Monthly Mean Hurricane Heat Potential Atlas based upon bathythermograph data for selected regions in the Tropical Atlantic and Pacific Oceans (this atlas also includes Mean Monthly Sea Surface Temperatures, Mean Monthly Depths of the 26C Isotherm, and Mean Monthly Layer Depths). The second objective is to compute chanages in sea surface temperature and in the convective layer depth which would be associated with heat loss from the ocean in a severe tropical storm passage. Upwelling effects upon these quantities has been considered by other authors.

II. APPROACH TO PROBLEM

A. GENERAL

1. Data

The data used in this thesis consist of monthly sea temperatures primarily from bathythermograph data taken at one-degree quadrangles at 100 feet levels down to 400 feet (Pacific) or 500 feet (Atlantic). The data was obtained from a report prepared by Margaret K. Robinson at Scripps Institution of Oceanography (S. I. O.). The Pacific data (last revision January 1972) was based primarily on mechanical bathythermograph observations collected at S.I. O. for the past 29 years from ships of the United States Navy and Coast Guard, and research vessels of scientific institutions. To a lesser degree, Robinson used data from expendable bathythermographs analyzed at Fleet Numerical Weather Central; exchange data from foreign institutions; hydrocast files from National Oceanographic Data Center; Eastropac STD data tapes, and data reports and Atlases. The North Atlantic data were based on the work of Elizabeth H. Schroeder of Woods Hole Oceanographic Institution (WHOI), and is not finished (last revision November, 1970).

2. Area of Investigation

The region selected involves the width of the Pacific Ocean from 5-30N latitude and the Atlantic Ocean from 5N to 40N latitude.

3. Units

Throughout this thesis, temperature will be expressed in degrees celsius; heat potential will be in calories per square centimeter column;

depth will be by meters or centimeters; specific heat at constant pressure will be in calories per gram-degree; density will be grams per cubic centimeter.

For computational simplification, density of sea water is assumed 1.0 gm/cm^3; and specific heat of sea water is assumed 1.0 cal/gm-degree. As a further simplification, when the 100 feet depth interval is expressed in meters, the depth is stated as 30 meters although the computations employ the more exact conversion of 30.48 meters.

4. Critical Hypothesis

Throughout this study values obtained are contingent upon the following:

26C Water: In order for hurricanes to receive heat from the ocean, an air-sea temperature differential must exist. Assuming that the approximate temperature of the air in the core of an average hurricane is 26C, then water temperature greater than 26C would be needed to provide input fuel to the hurricane.

4000 $cal/cm^2/day$ Hurricane Fuel Consumption: The assumption that an average hurricane consumes ocean heat at roughly the rate of 4,000 $cal/cm^2/day$ is based on previous studies.

It is recognized that the critical sea surface temperature and the heat lost per day may differ from hurricane to hurricane. However, the convenience of these simple and fairly accurate average values is believed to well justify the use of them.

Mathematical Relations: Heat potential computations are based on the iteration of the following relation:

$$Q = Cp \cdot \rho \cdot T \cdot Z$$

Where;

Q = Hurricane Heat Potential, (cal/cm^2).

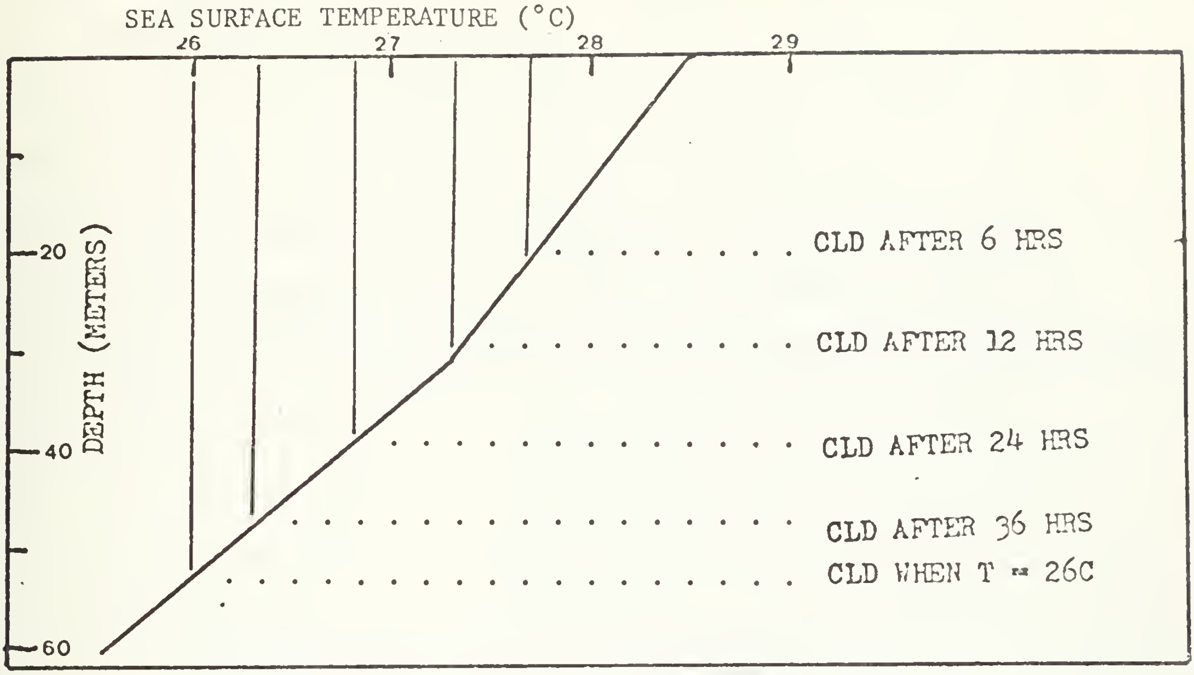
Cp = Specific Heat at Constant Pressure, (cal/gm-degree).

ρ = Density, (gm/cm^3)

T = Excess temperature over 26C (degrees celsius).

Z = Depth increment, (cm).

B. The Model - Main Analysis Program



SEPTEMBER MEAN THERMAL STURCTURE AT 9N 48W

FIGURE (1): THERMOSTRUCTURE SCHEMATIC SHOWING CHANGE IN CONVECTIVE LAYER DEPTH (CLD) AS INCREASING AMOUNTS OF HEAT ARE LOST.

Figure (1) schematically demonstrates the logic of the programs for sea surface temperature decrease and convective layer depth. Horizontal advection and upwelling effects are not considered - only the criterion that an average hurricane consumes one thousand cal/cm^2 for each six hour period. Further detailed explanations of the computer programs can be found in the Appendix.

Computer programs were made following the logic of Volgenau (1970) for heat potential computations and Jensen (1970) for sea surface temperature modification due to ocean heat loss to an average hurricane. From these computations contour plots were drawn using Mr. Perdue's computer plotting program used at Fleet Numerical Weather Central. Plots

of Hurricane Heat Potential, Sea Surface Temperature Modification, Convective Layer Depth, Sea Surface Temperature, and Mixed Layer Depth were made for each month of the year. However, in this thesis are included only plots of Monthly Mean Hurricane Heat Potential for each month of the year as well as plots for the month of August of Sea Surface Temperature Modification, Convective Layer Depth, Mean Sea Surface Temperature and Mean Layer Depth. The remaining plots are available in the Naval Postgraduate School Oceanography Department files.

III. DISCUSSION OF RESULTS

A. COMPARISONS OF MONTHLY CHARTS

In order to achieve a meaningful comparison of mean monthly heat potentials between the three tropical storm development regions, representative one degree quadrangles were selected within these areas and plotted as Figures (2) through (4). In comparing Figures (2), (3) and (4) (histograms of mean monthly heat potential for the Philippine Sea, Eastern Pacific and Caribbean Sea respectively) a similarity of patterns can be noted. In each a minimum of heat potential occurred in March followed by a maximum of heat in August. Figures (5), (6) and (7) (giving monthly frequency distributions of tropical cyclone occurrences for the Western Pacific, Eastern Pacific and North Atlantic respectively) show maximum occurrence of storms in the month of September.

From Figures (2), (3) and (4) it can be seen that month for month the Philippine Sea has the greatest heat potential. This is possibly related to the fact that as shown in Figure (8) there are more than three times as many tropical storms yearly in the Philippine Sea than in the Caribbean Sea.

In comparing the August mean hurricane heat potentials (Figure 20) with those calculated by Leipper and Volgenau (1972) for the individual years 1965-1968 it was found that the mean values were much lower. In fact, although Leipper and Volgenau found heat potentials of approximately 32,000 cal/cm^2 in the Gulf of Mexico, mean values did not exceed 15,000 cal/cm^2. Never-the-less, similar patterns were found between the mean heat potential plots and plots resulting from super-imposing the 15,000 cal/cm^2 ocean heat contours for all August cruises, 1965-1968. Leipper

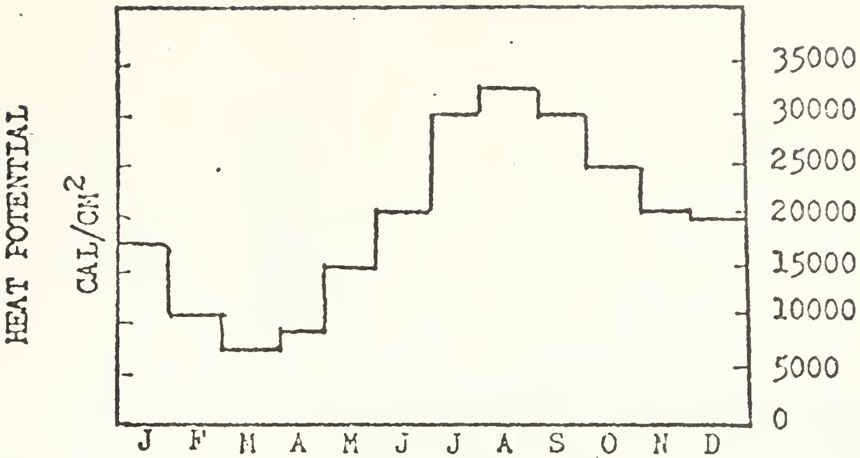


FIGURE (2): MEAN MONTHLY HEAT POTENTIAL HISTOGRAM
PHILIPPINE SEA (LAT 15N LONG 130E)

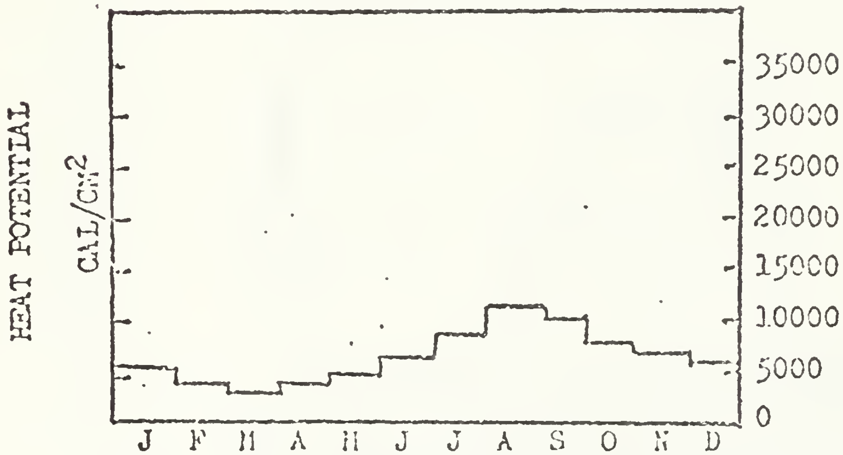


FIGURE (3): MEAN MONTHLY HEAT POTENTIAL HISTOGRAM
EASTERN PACIFIC - (LAT 15N LONG 100W)

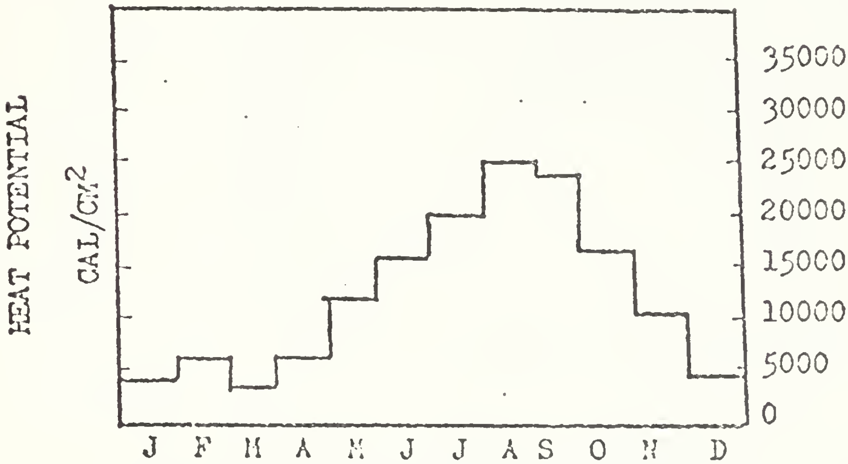


FIGURE (4): MEAN MONTHLY HEAT POTENTIAL HISTOGRAM
CARIBBEAN SEA (LAT 17N LONG 80W)

FIGURE (5): MONTHLY FREQUENCY DISTRIBUTION OF TROPICAL CYCLONE OCCURRENCES (1945-1969) WESTERN NORTH PACIFIC [BRAND 1972]

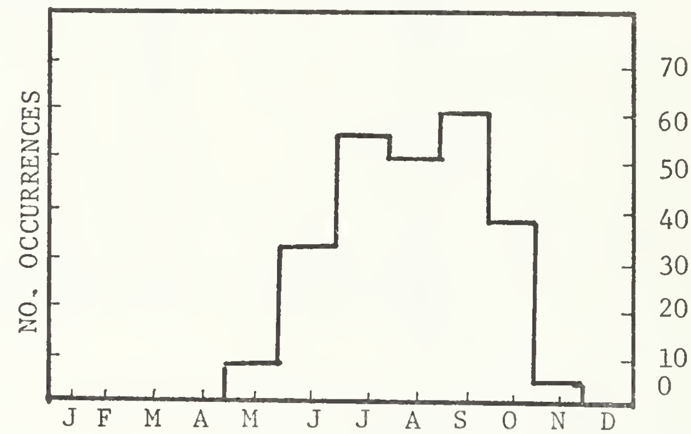


FIGURE (6): MONTHLY FREQUENCY DISTRIBUTION OF CYCLOGENESIS (1921-1971) - EASTERN PACIFIC [HANSEN 1972]

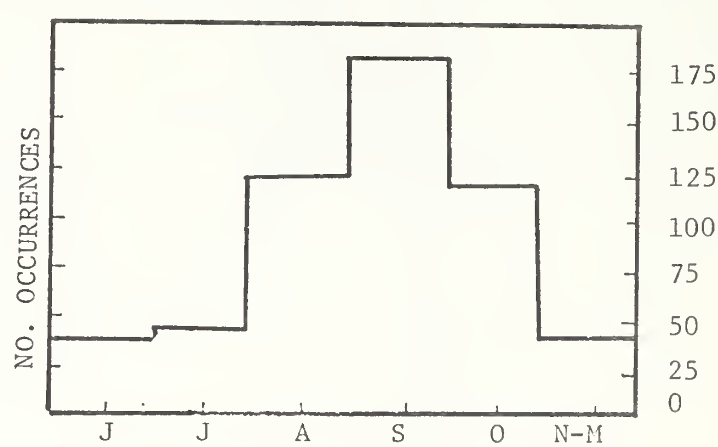


FIGURE (7): MONTHLY FREQUENCY DISTRIBUTION OF TROPICAL CYCLONE OCCURRENCES (1901-1963) - NORTH ATLANTIC [CRY 1965]

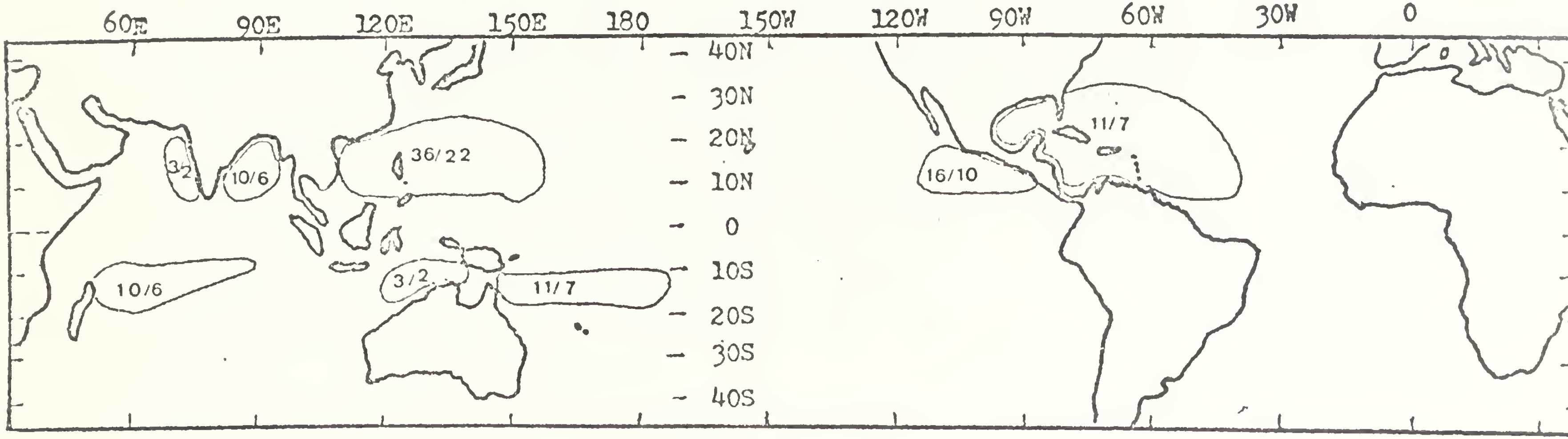


FIGURE (8): DESIGNATION OF TROPICAL STORM DEVELOPMENT REGIONS. NUMBER PRECEDING SLASH IS PERCENTAGE OF TROPICAL STORMS OCCURRING IN EACH REGION RELATIVE TO THE GLOBAL TOTAL. SECOND NUMBER IS THE AVERAGE NUMBER OF TROPICAL STORMS OCCURRING IN EACH REGION PER YEAR. [GRAY 1967]

and Volgenau found two areas, one just north of the western tip of Cuba and one midway across the Gulf of Mexico north of Yucatan, had potentials greater than 15,000 cal/cm^2 in each of the four years observed. The mean heat potential plots had warm centers in excess of 12,000 cal/cm^2 in two areas, one located off the western tip of Cuba and the other just northwest of the warm center that existed during the 1965-1968 period.

The tongue of high potential (greater than 15,000 cal/cm^2) that Leipper and Volgenau found running from the western tip of Cuba toward the Mississippi Delta in individual years was not apparent in the August mean heat potential plot. It is interesting to note that the September mean heat potential plot (Figure 21) had this characteristic warm tongue, although all values were less than 16,000 cal/cm^2.

Analysis of the 12 monthly hurricane heat potential plots for the North Atlantic (Figures 13-24) reveals that south of Cuba sufficient heat exists in every month to support a hurricane for twenty - four hours. This is not true for the Gulf of Mexico where heat potentials of 4,000 cal/cm^2 or greater exist only from June through November.

In the North Eastern Pacific, warm centers migrate from month to month. Starting in January, the warm center (greater than 4,000 cal/cm^2) migrates in a southwest direction. By April this warm center has increased in heat content (greater than 8,000 cal/cm^2) and migrated approximately six hundred miles to the 120W meridian. From April to May the heat potential plot shows a dramatic change. The warm center has shifted direction and magnitude. It now migrates towards the Mexican coast in an easterly direction, moving over four hundred miles in one month. The May heat potential values in the center exceed 12,000 cal/cm^2. The warm center continues to move eastward, but by July the center has

"cooled" to less than 12,000 cal/cm^2. The August warm center has migrated east of the 106W meridian and once again contains values in excess of 12,000 cal/cm^2. By November the center has cooled to less than 8,000 cal/cm^2, but in December the 8,000 cal/cm^2 center reappears.

The migrating warm centers which characterized the Eastern Pacific were not typical of any other area. The Western Pacific was characterized as having stable warm centers 24-32 thousand cal/cm^2 east of the Philippine Islands during all twelve months of the year. The North Atlantic had warm centers which varied in magnitude seasonally (4,000-24,000 cal/cm^2) but always remained south of Cuba.

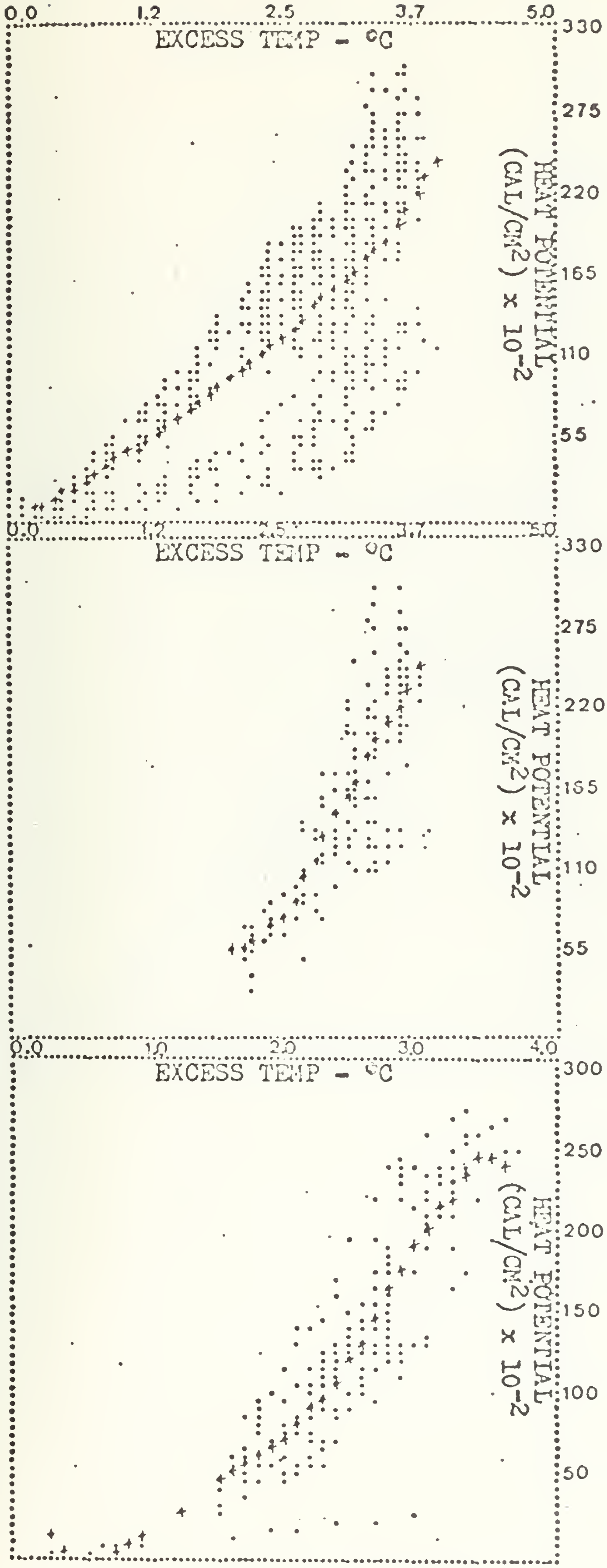
B. CORRELATIONS BETWEEN PARAMETERS

In an attempt to evaluate possible correlations between sea surface temperature (T), heat potential (Q), and depth of the 26C isotherm (Z), a computer subprogram was used to plot combinations of T vs Q, T vs Z, and Z vs Q. If any such correlations exist they would provide a convenient means of estimating heat potential from the simpler and more readily available quantities T and Z.

1. Data Presentation

At first data were selected geographically by 5 degree bands from 5N-30N extending across both the Atlantic and Pacific Ocean. The months of August and November were chosen for analysis. Since the results were encouraging, further analysis was made, this time by selected Oceanographic regions having fairly uniform water mass characteristics. Three areas in each ocean were selected; South China Sea (Lat 5-20N, Long 110-117E), Philippine Sea (Lat 15-25N, Long 120-135E), Eastern Pacific (Lat 10-20N, Long 110-120W), Gulf of Mexico (Lat 20-30N, Long 100-85W). Caribbean Sea (Lat 5-20N, Long 90-65W), and Eastern Atlantic (Lat 5-20N, Long 45-15W).

A characteristic of the UTPLOT subprogram used in displaying the data in figures (9) through (11) is that multiple points are plotted, one on the other, so that there appears to be only one data point for a fix T vs Q (for example) when in fact there could be any number of points. In order to ascertain the true relationship, the LSQPL2 subprogram was used to determine a least square fit for all of the data, This curve, superimposed on the data, is represented by crosses. Tables (1) through (3) were constructed by selecting values for the independent variable (T) or (Z), then determining the corresponding dependent variable

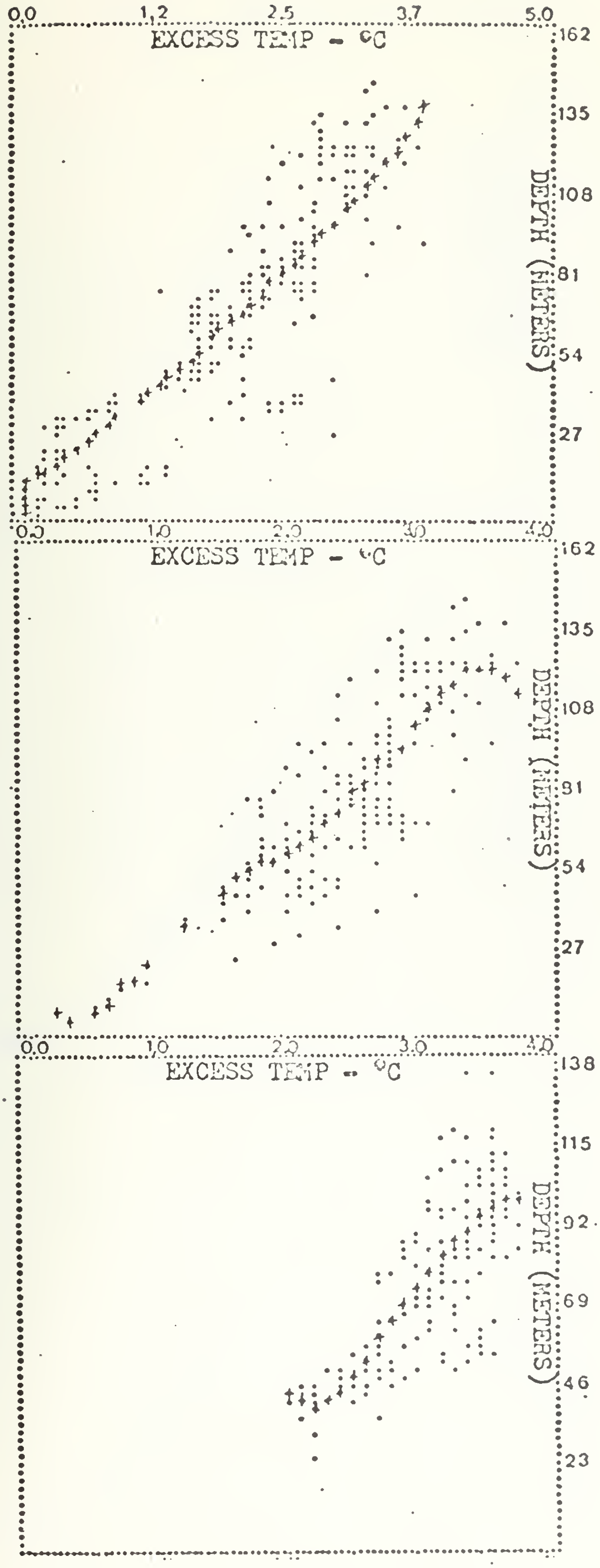


PACIFIC OCEAN - LAT 15N-20N

PHILIPPINE SEA

CARIBBEAN SEA

FIGURE (9): CORRELATION PLOT OF SEA SURFACE TEMPERATURE VS. HEAT POTENTIAL AUGUST

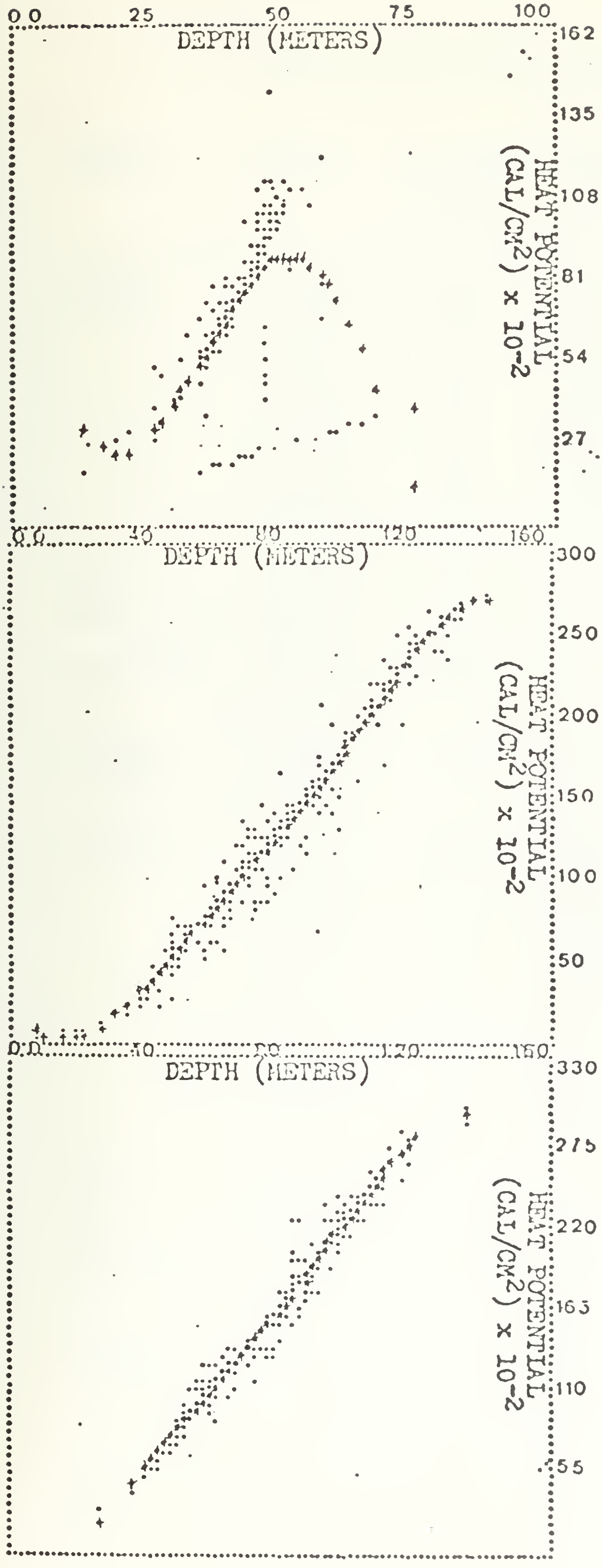


ATLANTIC OCEAN
LAT 15N-20N

CARIBBEAN SEA

PHILIPPINE SEA

FIGURE (10): CORRELATION PLOT OF SEA SURFACE TEMPERATURE VS. DEPTH OF 26C ISOTHERM - AUGUST



GULF OF MEXICO

CARIBBEAN SEA

PHILIPPINE SEA

FIGURE (11): CORRELATION PLOT OF DEPTH OF 26C ISOTHERM VS. HEAT POTENTIAL AUGUST

TABLE (1) - HEAT POTENTIAL (cal/cm^2) FOR DIFFERENT VALUES OF SEA SURFACE TEMPERATURE - AUGUST

REGION	BOUNDARY	NO. DATA POINTS	SEA SURFACE TEMPERATURE 27C	28C	29C	29.5C
PACIFIC	5N-10N	1033	370	8980	22500	27730
	10N-15N	914	1480	7500	11760	30000
	15N-20N	537	1110	5970	19120	30000
	20N-25N	271	1110	5600	14630	25460
	25N-30N	137	740	4120	13470	17590
SOUTH CHINA SEA	5N-20N 100E-117E	124	-	3250	7250	-
PHILIPPINE SEA	15N-25N 120E-135E	168	-	-	10500	22130
EASTERN PACIFIC	5N-20N 110W-120W	160	1125	-	-	-
ATLANTIC	5N-10N	286	2250	7910	-	-
	10N-15N	392	1000	6400	15600	-
	15N-20N	327	1110	8240	17220	26980
	20N-25N	276	1110	5970	15375	* 24350 19490
	25N-30N	271	1110	1710	8240	* 17590 16110
GULF OF MEXICO	20N-30N 100W-85W	128	-	1400	* 6400 2200	* 10800 3600
CARIBBEAN SEA	5N-20N 90W-65W	217	740	7130	18400	26620
EASTERN ATLANTIC	5N-20N 45W-15W	361	* 2270 1120	-	-	-

*Two values were read from the plot due to recurvature

TABLE (2) - DEPTH 26C ISOTHERM (METERS) FOR DIFFERENT VALUES OF SEA SURFACE TEMPERATURE - AUGUST

REGION	BOUNDARY	NO. DATA POINTS	SEA SURFACE TEMPERATURE 27C	28C	29C	29.5C
PACIFIC	5N-10N	1033	37.0	66.60	104.6	142.6
	10N-15N	914	-	* 89.8 56.0	112.5	119.9
	15N-20N	537	14.8	* 72.3 29.6	104.6	119.9
	20N-25N	271	7.4	* 37.5 11.1	86.1	104.6
	25N-30N	137	14.8	37.5	63.9 * 48.6	71.6
SOUTH CHINA SEA	5N-20N 110E-117E	124		31.7	64.0	43.6
PHILIPPINE SEA	15N-25N 120E-135E	168	-	45.2	74.8	98.5
EASTERN PACIFIC	5N-20N 110W-120W	160	38.1	31.7	-	-
ATLANTIC	5N-10N	286	30.0	58.1	60.0	-
	10N-15N	392	28.0	50.0	74.0	-
	15N-20N	327	34.8	64.1	95.8	117.4
	20N-25N	276	36.75	53.3	61.4	61.4
	25N-30N	271	21.8	35.0	46.8	50.0
GULF OF MEXICO	20N-30N 100W-85W	128	-	-	45.2	41.6
CARIBBEAN SEA	5N-20N 90W-65W	217	24.0	58.7	101.4	120.0
EASTERN ATLANTIC	5N-20N 45W-15W	361	30.0	50.0	-	-

*Two values were read from the plot due to recurvature

TABLE (3) HEAT POTENTIAL (cal/cm^2) FOR SELECTED DEPTHS OF 26C ISOTHERM (METERS) - AUGUST

REGION	BOUNDARY	NO. DATA POINTS	DEPTH OF 26C 30m	60m	100m	120m
PACIFIC	5N-10N	1033	1850	8980	25460	29700
	10N-15N	914	1850	9350	19140	27730
	15N-20N	537	1110	9350	20600	27360
	20N-25N	271	1480	11500	22500	-
	25N-30N	137	3380	11620	-	-
SOUTH CHINA SEA	5N-20N 110E-117E	124	4100	11478	-	-
PHILIPPINE SEA	15N-25N 120E-135E	168	3400	11550	22500	27500
EASTERN PACIFIC	5N-20N 110W-120W	160	3700	5300	-	-
ATLANTIC	5N-10N	286	1800	7600	-	-
	10N-15N	392	2000	8000	16800	24000
	15N-20N	327	1500	7000	18000	23500
	20N-25N	276	2500	8500	19000	24500
	25N-30N	271	3600	1000	-	-
GULF OF MEXICO	20N-30N 100W-85W	128	4000	7200	-	-
CARIBBEAN SEA	5N-20N 90W-65W	217	2000	8500	18000	23500
EASTERN ATLANTIC	5N-20N 45W-15W	361	1600	7600	-	-

TABLE (4) - OCEANIC CHARACTERISTICS OF MAXIMUM TYPHOON INTENSIFICATION REGIONS OF THE NORTH WESTERN PACIFIC

MONTH	REGION LAT LONG	HEAT POTENTIAL (CAL/CM^2) x 10^{-2}	DEPTH 26C ISOTHERM METERS	LAYER DEPTH METERS	SEA SURFACE TEMPERATURE °C
JULY	13N-17N 152E-158E	160-280	120+	60-75	28-29
AUGUST	12N-17N 162E-172E	160-200	90-105	60+	28+
	5N-14N 130E-145E	240-320	105-120	60+	29+
SEPTEMBER	5N-12N 161E-170E	180-240	90+	60+	28-29
	5N-18N 156E-173E	160-240	90-120	60+	28-29
	5N-11N 151E-132E	240-320	90-105	60-75	29+
OCTOBER	8N-12N 142E-150E	200-280	90-120	60	29+
NOVEMBER	5N-10N 132E-142E	240-320	105+	60+	29-30
	8N-16N 153E-164E	200-320	90-120	60-75	28-29

TABLE (5) - OCEANIC CHARACTERISTICS OF LOW - LATITUDE TYPHOON WEAKENING REGIONS OF THE NORTH WESTERN PACFIC

MONTH	REGION LAT LONG	HEAT POTENTIAL (CAL/CM^2) x 10^{-2}	DEPTH 26C ISOTHERM METERS	LAYER DEPTH METERS	SEA SURFACE TEMPERATURE °C
JULY	20N-30N 110E-130E	40-60	30-75	15-30	27-29
	26N-30N 130E-150E	0-40	0-45	15-30	26-28
AUGUST	20N-30N 110E-130E	40-240	30-75	30-45	29
	27N-30N 130E-158E	40-80	15-75	15-30	27-28
SEPTEMBER	18N-30N 110E-130E	40-200	60-90	30-60	28-29
	23N-30N 130E-140E	40-120	30-60	30-45	28-29
	22N-30N 150E-140E	40-120	30-60	30-45	27-28
OCTOBER	10N-30N 110E-120E	40-120	30-75	30-45	27-28
	20N-30N 120E-140E	40-120	30-75	30-60	27-28
	25N-30N 140E-160E	40-100	45-60	45-75	27-28
NOVEMBER	18N-30N 110E-120E	0-40	0-75	45-75	24-27
	15N-30N 120E-130E	0-200	0-105	45-75	24-29
	18N-30N 130E-160E	0-160	0-90	60-75	24-28

(Q) or (Z) by reading from the plot the value at the intersection of the least square curve and the independent variable. Sea Surface temperature is plotted in degrees celsius for values in excess of 26 C. Heat Potential is plotted in $(cal/cm^2) \times 10^{-2}$. Depth of the 26C isotherm is in meters.

2. Description of Results

T vs. Q As indicated in Table (1), knowledge of sea surface temperature does not lead to a positive determination of heat content in the ocean. The general pattern indicates an increase in heat content with increased sea surface temperature, however, a decrease in heat content is noted with increased latitude for a given sea surface temperature. The data when different regions are compared show no consistency in the relationship between sea surface temperature and heat content. The scatter diagrams of T vs. Q, Figure (9), show a wide range of heat values for given values of temperature. It is interesting to note that the Pacific data for Lat 15-20N show a near linear least square approximation. Also a straight line can be used to approximate the upper boundary of the data point scatter.

T vs. Z Table (2) shows trends similar to those shown in Table (1). As a rule, the higher the sea surface temperature, the deeper is the 26C isotherm. For a given sea surface temperature, the depth of the 26C in the Atlantic does not show as regular a pattern of decreasing depth with increased latitude as is the case in the Pacific. The scatter diagrams for T vs. Z, Figure (10), show a wide spread of values about the least square curve indicating a poor correlation between sea surface temperature and depth of the 26C isotherm in all regions.

Z vs. Q By far the best correlation of data was found between the depths of the 26C isotherm and heat potential. Table (3) shows a consistent increase of heat content with increased depth. Further, the data reveals a close correlation of values between latitude bands and also a good correlation between oceanographic regions. Figure (11) shows that with the exception of the Gulf of Mexico, there is an excellent grouping of data about the least square curve. The correlation plot in the Gulf of Mexico might be taken to indicate that there is more than one water mass present in the upper layers which is indeed the case (Leipper, 1970).

A study of the above mentioned relationships for other months (April, July, October) revealed the same pattern that existed for August. In a selected region, the correlation between parameters of T, Q, and Z remained nearly as good for the different months. This is not to imply that given a sea surface temperature that the corresponding heat potential and depth of 26C were the same for each month. On the contrary, it was found that August values for Z and Q were the highest for a given sea surface temperature and these values varied seasonally.

C. SEVERE TROPICAL STORM INTENSIFICATION RELATED TO HURRICANE HEAT POTENTIAL

Brand (1972) analyzed track segments of thirty typhoons in the Western Pacific (1945-1969) covering the period forty-eight hours prior to reaching the Philippines to twenty-four hours after leaving the islands. Brand noted an average increase in intensity during the period forty-eight to twenty-four hours prior to reaching the Philippines. Over water, winds reached and maintained a speed of ninety-two knots. Over land, the average intensity decreased to about sixty-two knots. After this 33% reduction, the intensity increased again in the South China and Sulu Seas.

In addition, Brand examined the average speed of movement of these typhoons and determined that there was a decrease in speed until about twenty hours before reaching the islands, then there was a slight (10%) acceleration when the Philippines were approached. There was a decrease in speed as the storm passed over the Philippines and moved into the Sourth China and Sulu Seas.

These studies show distinct geographical and seasonal preferences for both rapid intensification (fifty knots or more in twenty-four hours) and low - latitude weakening (twenty - knots or more in twenty-four hours) of tropical cyclones.

Table (4) gives values of various oceanic parameters for the respective areas of maximum typhoon intensification. In all instances these areas were characterized by exceeding the following minima: hurricane heat potential of 16,000 cal/cm^2, depth of the 26C isotherm of ninety meters, layer depth of sixty meters and sea surface temperature of twenty-eight degrees celsius.

Table (5) gives values of various oceanic parameters for the respective areas of low-latitude weakening of typhoons. These areas were characterized by the following minima: hurricane heat potential of 0-4000 cal/cm^2, depth of the 26C isotherm thirty meters or less in eleven of thirteen cases, layer depth forty-five meters or less in twelve of thirteen cases and thirty meters or less in nine and sea surface temperature of 27C or less in ten of thirteen cases.

Comparative analysis of the maxima and minima of heat potential and depth of the 26C isotherm revealed that areas of typhoon intensification are characterized by deep, warm water and areas of low - latitude weakening of typhoons are characterized by relatively shallow, cool water.

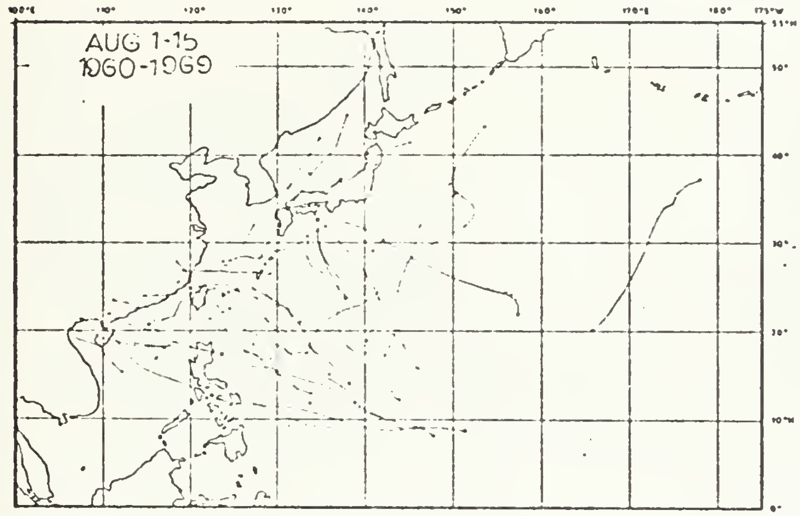
Figures (58) and (59), historical plots of August severe tropical storms for the Western Atlantic and Pacific, give an indication of the "mean pattern" of the August storms. No obvious relationship was noted between these tracks and the August mean heat potential plots, Figures (20) and (43).

D. CALCULATED CHANGES IN SEA SURFACE TEMPERATURE AND CONVECTIVE LAYER DEPTH AFTER PASSAGE OF A SEVERE TROPICAL STORM

The Sea Surface Temperature Modification Program was designed to calculate the range of sea surface temperature changes resulting from the heat loss to severe tropical storms under different initial conditions. The Convective Layer Program was designed to calculate the depth of the warm, highly mixed water generated in various regions in the wake of severe tropical storms assuming average initial conditions. This information would have much direct usefulness in such areas as Naval operations, weather forecasting and fisheries.

The data from these two programs, when plotted, graphically demonstrate the extent of the geographic area of the ocean which can be changed due to heat lost to hurricanes and typhoons. It can be seen that researchers would arrive at different conclusions as to severe tropical storm affects to the thermal structure depending upon the area investigated. Analysis of the various monthly plots revealed that in areas of high hurricane heat potential there is less measureable affect upon the ocean thermal structure during the passage of severe tropical storms than in areas of low heat potential. Closer analysis revealed that areas of iso-heat potential may have dissimilar convective depths and sea surface temperature

FIGURE (58): HISTORICAL PLOT OF TROPICAL STORMS AND TYPHOON TRACKS, AUGUST - WESTERN PACIFIC [LIECHTY 1972]



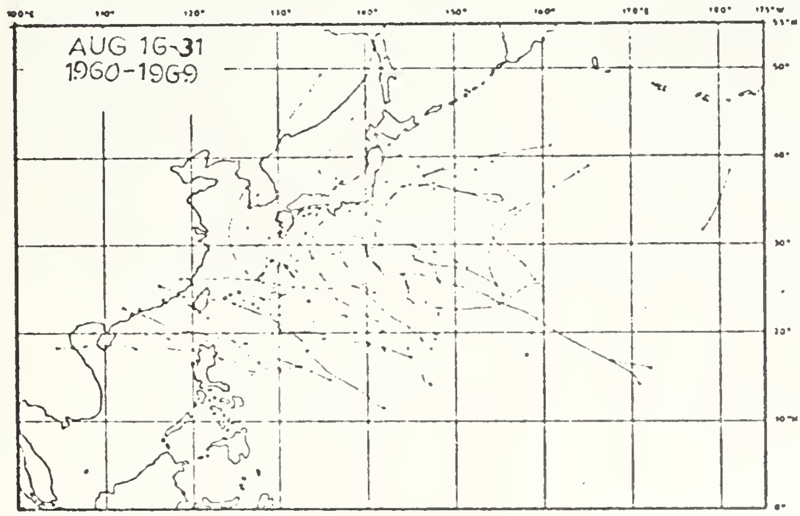
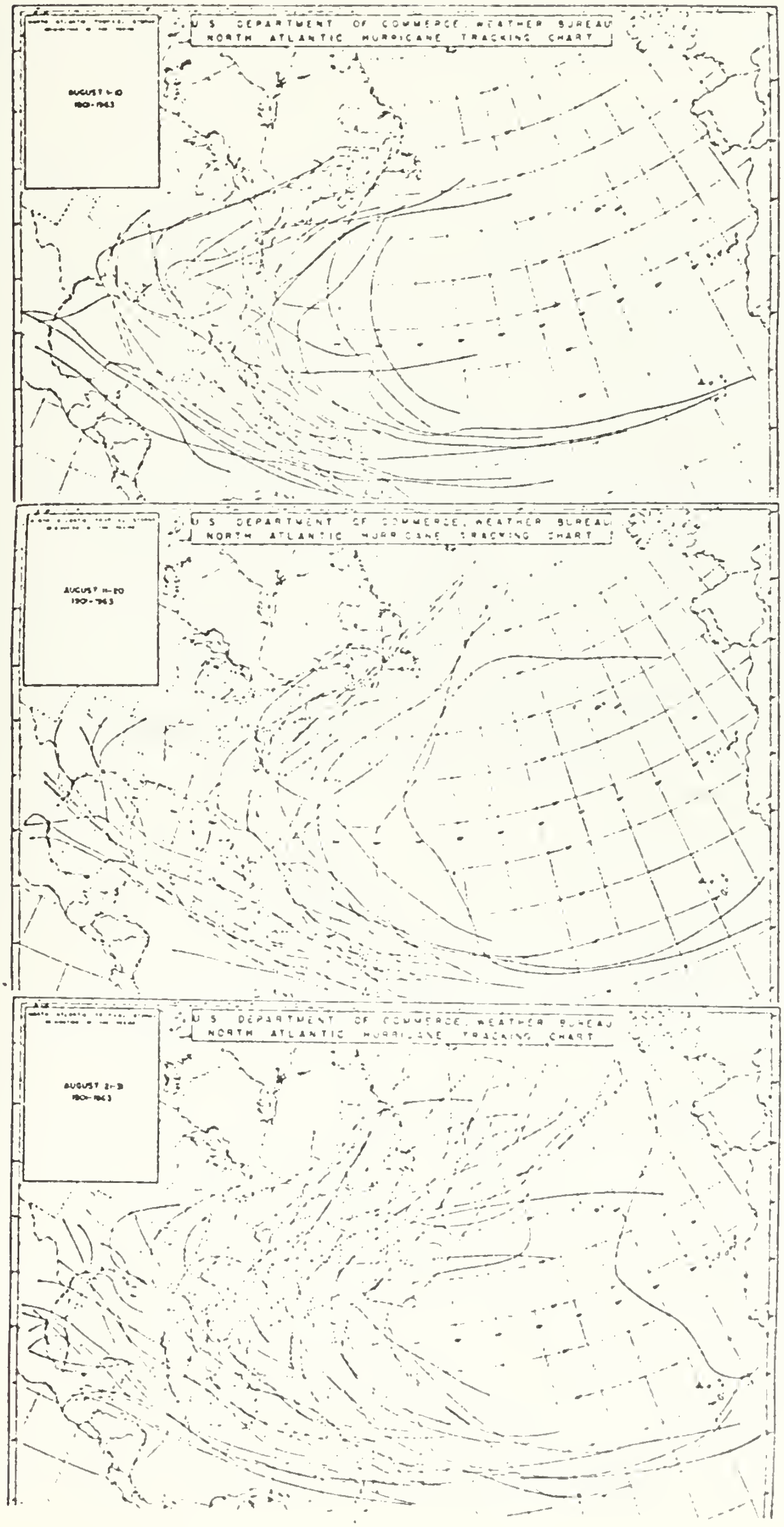


FIGURE (59): HISTORICAL PLOT OF HURRICANE TRACKS, AUGUST - WESTERN ATLANTIC [CRY 1965]



modification depending upon the initial thermal gradient. The thermal gradient must be considered when computing hurricane affects.

An analysis of August values was performed. August was selected because it marks the beginning of the main severe tropical storm season.

Depths to which heat loss to the storm affects modified the thermal structure varied from fifteen to sixty meters for a twelve hour storm. Given a twenty-four hour storm, or two successive twelve hour storms, then the depths affected extend to a maximum of seventy-five meters - with thirty to forty-five meters being the most prevalent over the area. The maximum sea surface temperature reduction due to this storm passage was a little over three degrees celsius but this also varied monthly.

These tropical storm affects can persist for several weeks according to Leipper (1967) and Hazelworth (1968). This time probably depends on such factors as the speed, size, and intensity of the storm as well as the initial mixed layer depth and the temperature gradient of the thermocline (and a few other atmospheric features).

IV. CONCLUSIONS

1. Areas of typhoon intensification are characterized by deep, warm water and areas of low-latitude weakening are characterized by presence of some relatively shallow, cool water.

2. In areas of high hurricane heat potential the calculated affects upon the ocean thermal structure during passage of tropical storms was less than in areas of low heat potential.

3. Twenty-four hour affects of 4,000 cal/cm^2/day heat consumption caused the sea surface temperature to drop a negligible amount in some areas to more than three degrees celsius in others depending upon initial sea temperature structure. The thermal affects reached a depth of over ninety meters in some areas - and in other areas only depths less than fifteen meters were affected.

4. The known tropical storm development regions were characterized by a heat potential maximum in August and sufficient heat to sustain a hurricane in each month of the year.

5. There existed only a poor correlation between sea surface temperature and corresponding heat potential for a particular area.

6. Warm, deep centers of water with heat potential values in excess of 32,000 cal/cm^2 existed east of the Philippine Islands during the months of July through November. In the Western Atlantic warm, deep centers in excess of 24,000 cal/cm^2 existed south of Cuba during the months of August through October.

7. In comparing the August mean hurricane heat potentials with those calculated by Leipper and Volgenau (1972) for the individual years 1965-1968 it was found that the mean values were much lower. They

found heat potentials as high as 32,000 cal/cm^2 in the Gulf of Mexico whereas mean values did not exceed 15,000 cal/cm^2.

8. In the North Eastern Pacific, warm centers of hurricane heat potential (4,000-12,000 cal/cm^2) migrated from month to month.

9. The Western Pacific was characterized as having stable warm centers of hurricane heat potential (24,000-32,000 cal/cm^2) east of the Philippine Islands during all twelve months of the year.

10. The North Atlantic had warm centers of hurricane heat potential (4,000-24,000 cal/cm^2) which varied in magnitude seasonally but always remained south of Cuba.

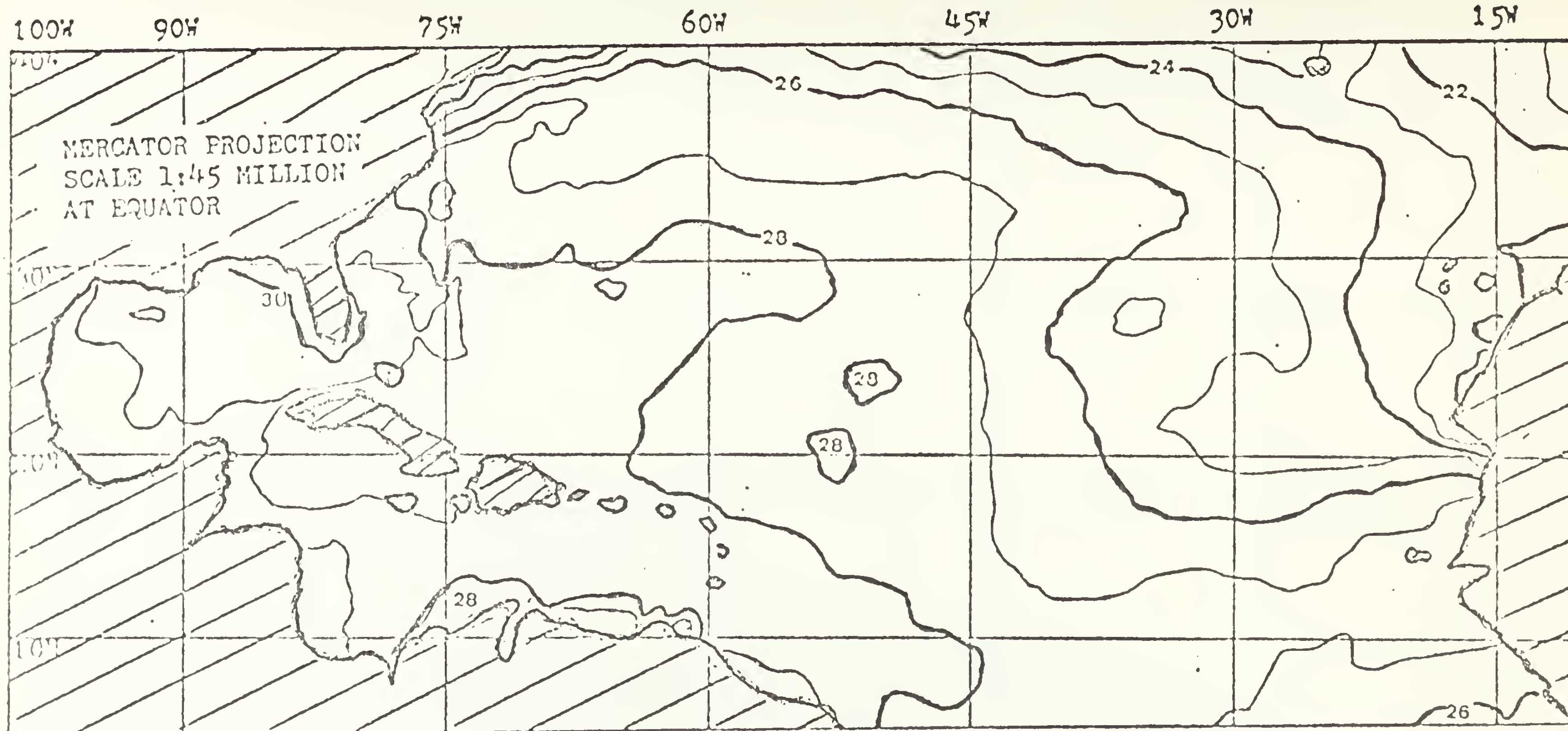
V. RECOMMENDATIONS

It is recommended that:

1. A pattern of airborne expendable bathythermographs be strategically dropped across tropical storm tracks, before and after passage of storms, in order to increase the present completely inadequate data base on thermal structure modifications due to severe tropical storms.

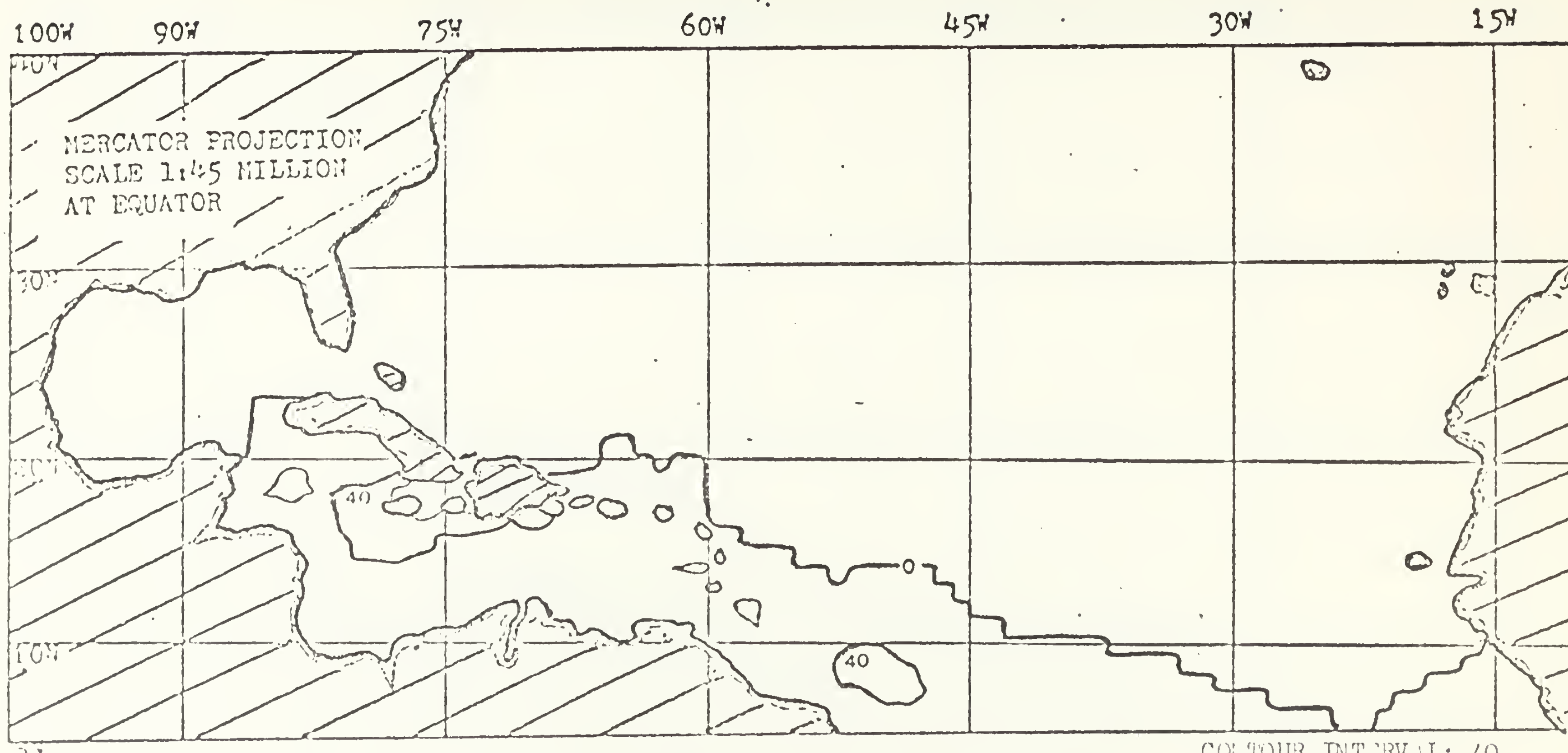
2. Continued studies be made using the hurricane heat potential concept. The monthly mean values should be compared with values in selected years to determine if significant yearly variability exists and if differences in severe tropical storms from year to year are associated with ocean differences.

3. Mr. James N. Perdue's Ocean Plot Program used extensively for this theses at Fleet Numerical Weather Central be adapted for the IBM 360 computer so that Naval Postgraduate School students can have an ocean plot program.



(CONTOUR INTERVAL: 1C)

FIGURE (12): AUGUST MEAN SEA SURFACE TEMPERATURE, NORTH ATLANTIC



CONTOUR INTERVAL: 40
UNITS: cal/cm^2 x 10^{-2}

FIGURE (13): JANUARY MEAN HURRICANE HEAT POTENTIAL, NORTH ATLANTIC.

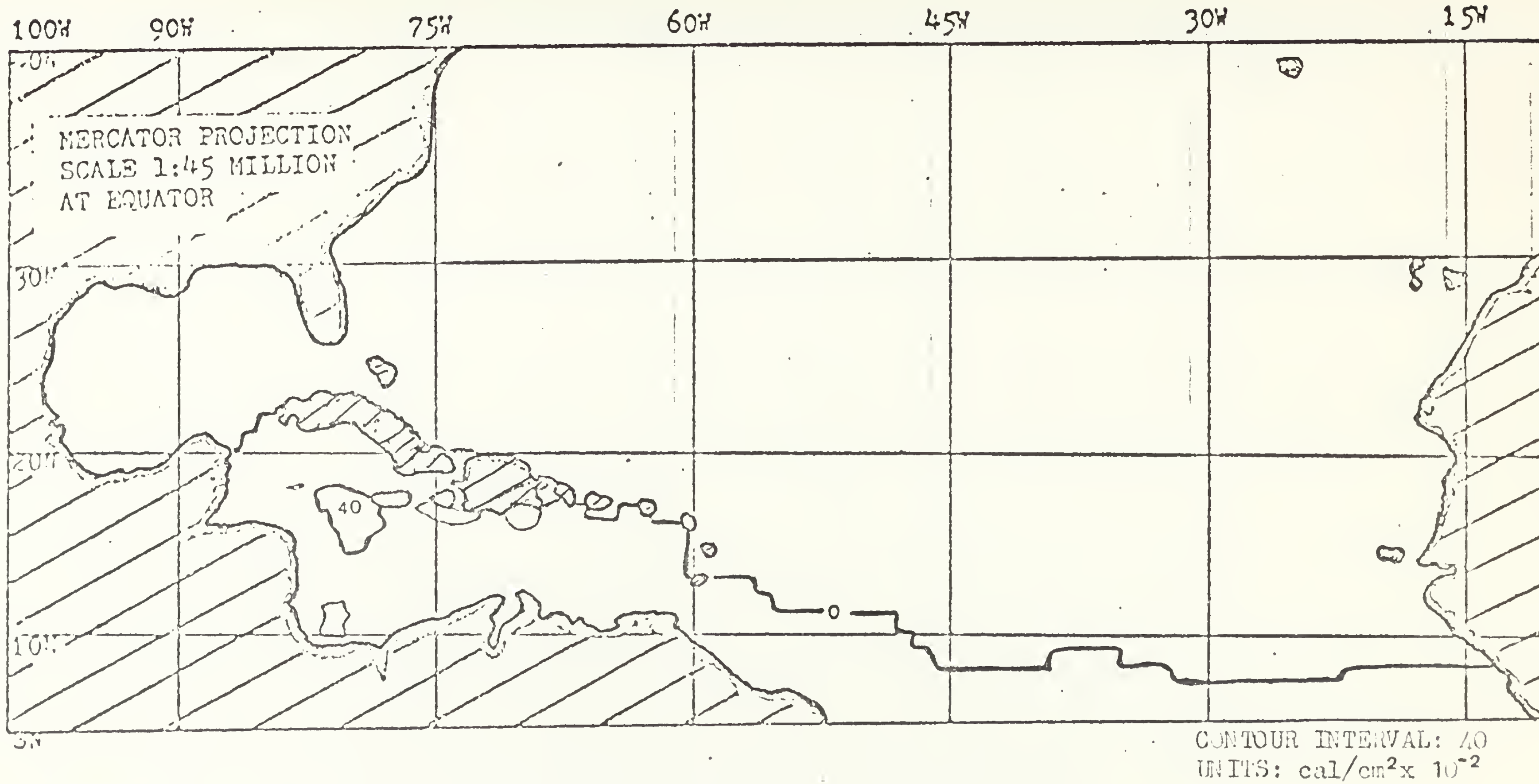
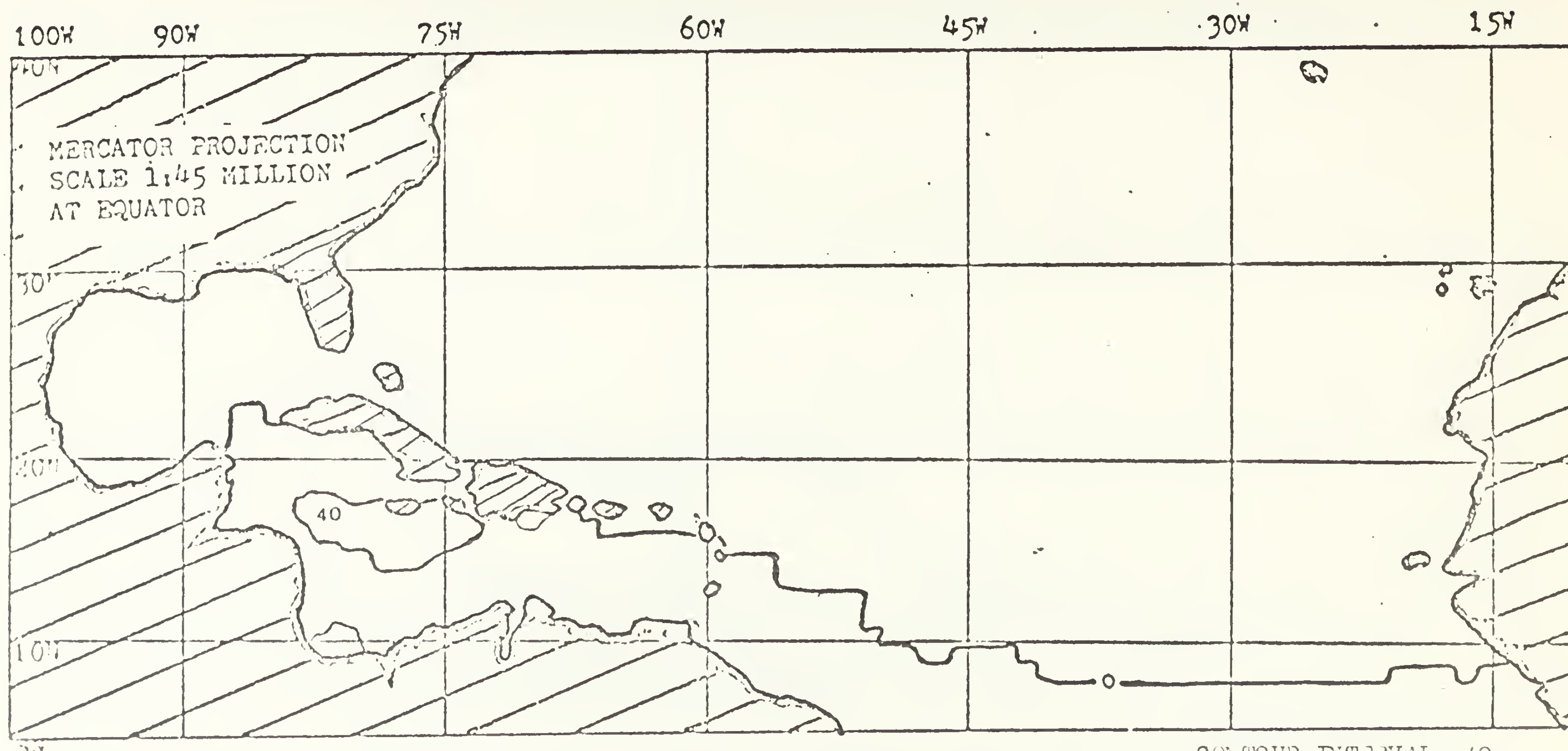


FIGURE (14): FEBRUARY MEAN HURRICANE HEAT POTENTIAL, NORTH ATLANTIC.



CONTOUR INTERVAL: 40
UNITS: cal/cm^{2}x 10^{-2}

FIGURE (15): MARCH MEAN HURRICANE HEAT POTENTIAL, NORTH ATLANTIC.

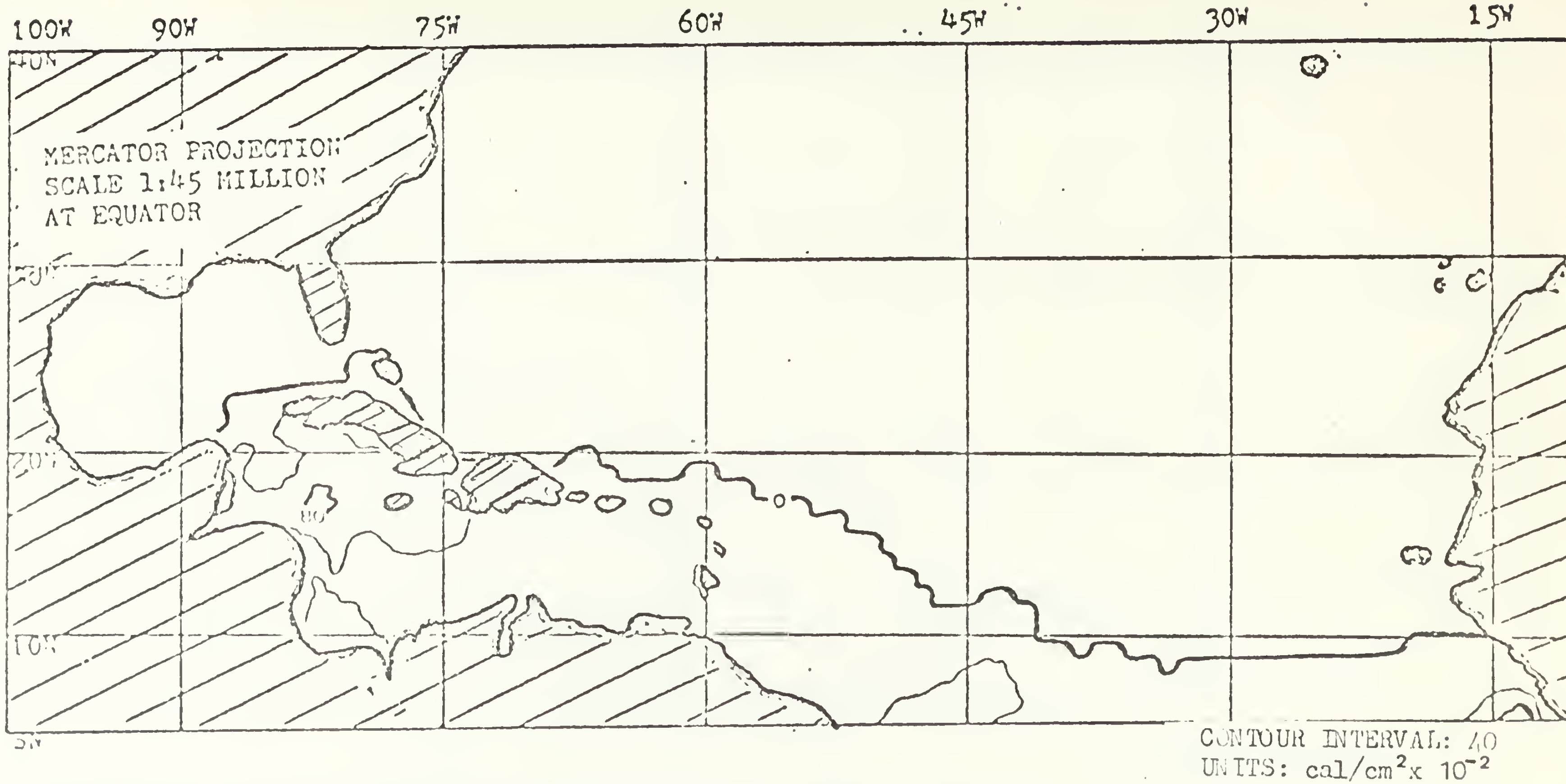
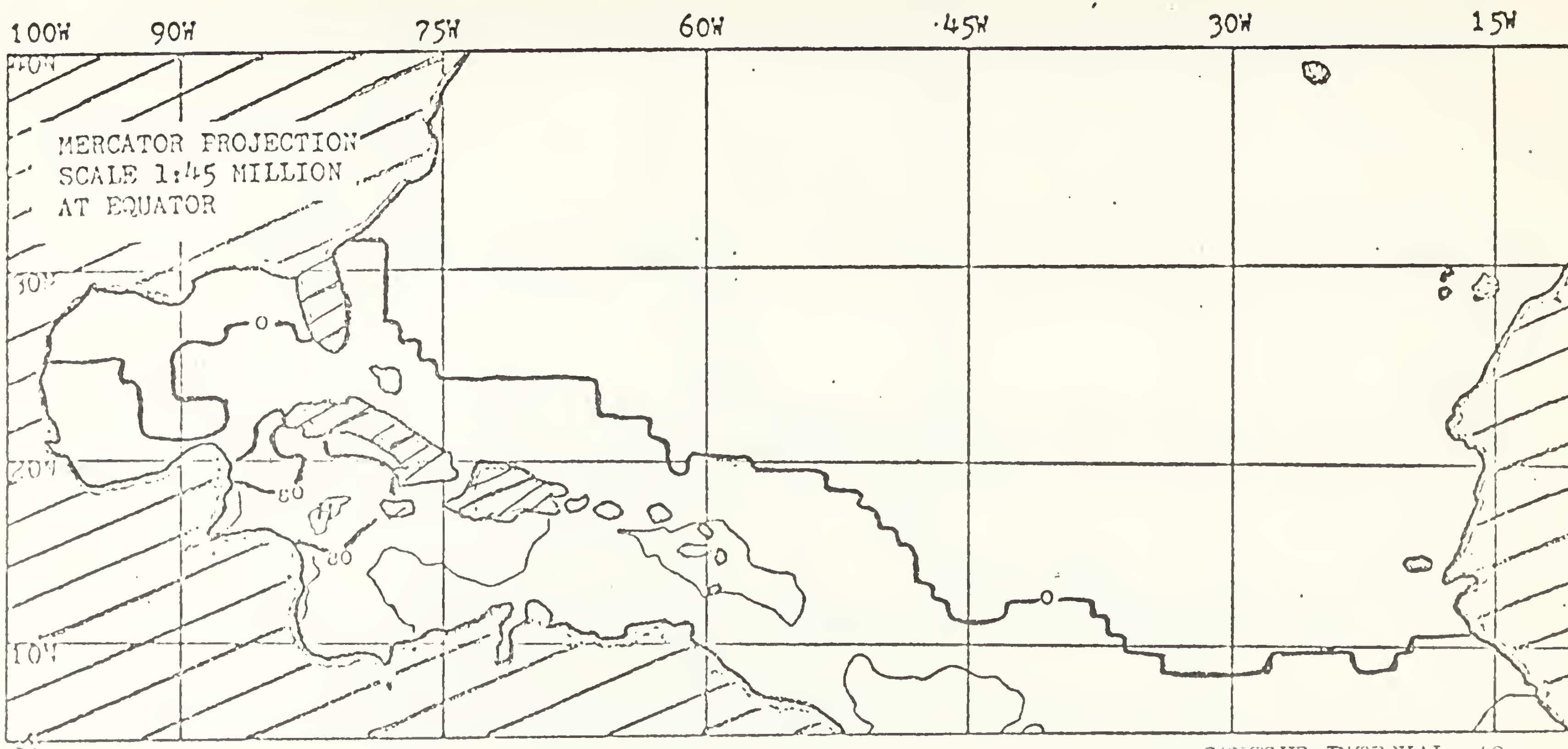


FIGURE (16): APRIL MEAN HURRICANE HEAT POTENTIAL, NORTH ATLANTIC.



CONTOUR INTERVAL: 40
UNITS: $cal/cm^2 x 10^{-2}$

FIGURE (17): MAY MEAN HURRICANE HEAT POTENTIAL, NORTH ATLANTIC.

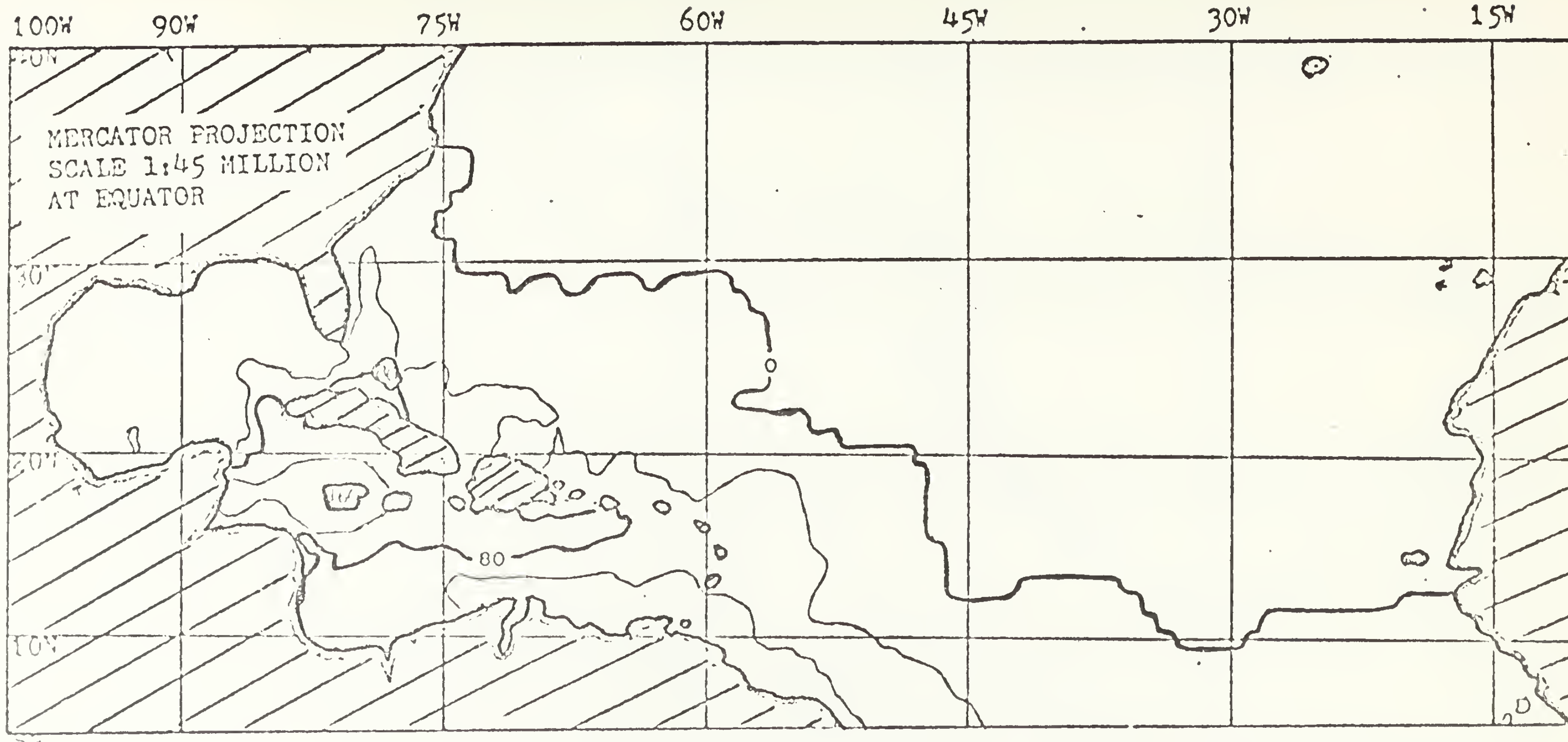


FIGURE (18): JUNE MEAN HURRICANE HEAT POTENTIAL, NORTH ATLANTIC.

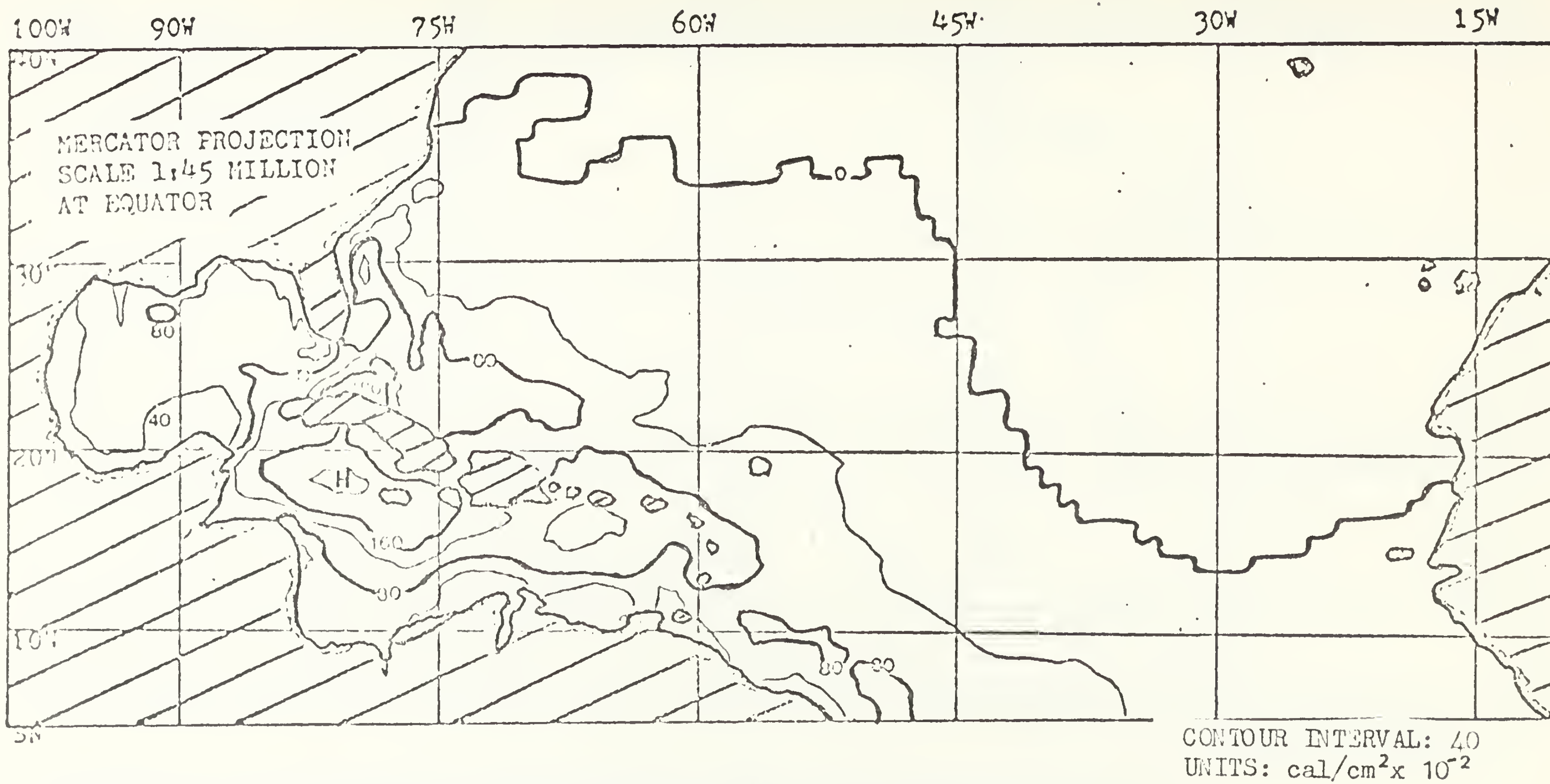


FIGURE (19): JULY MEAN HURRICANE HEAT POTENTIAL, NORTH ATLANTIC.

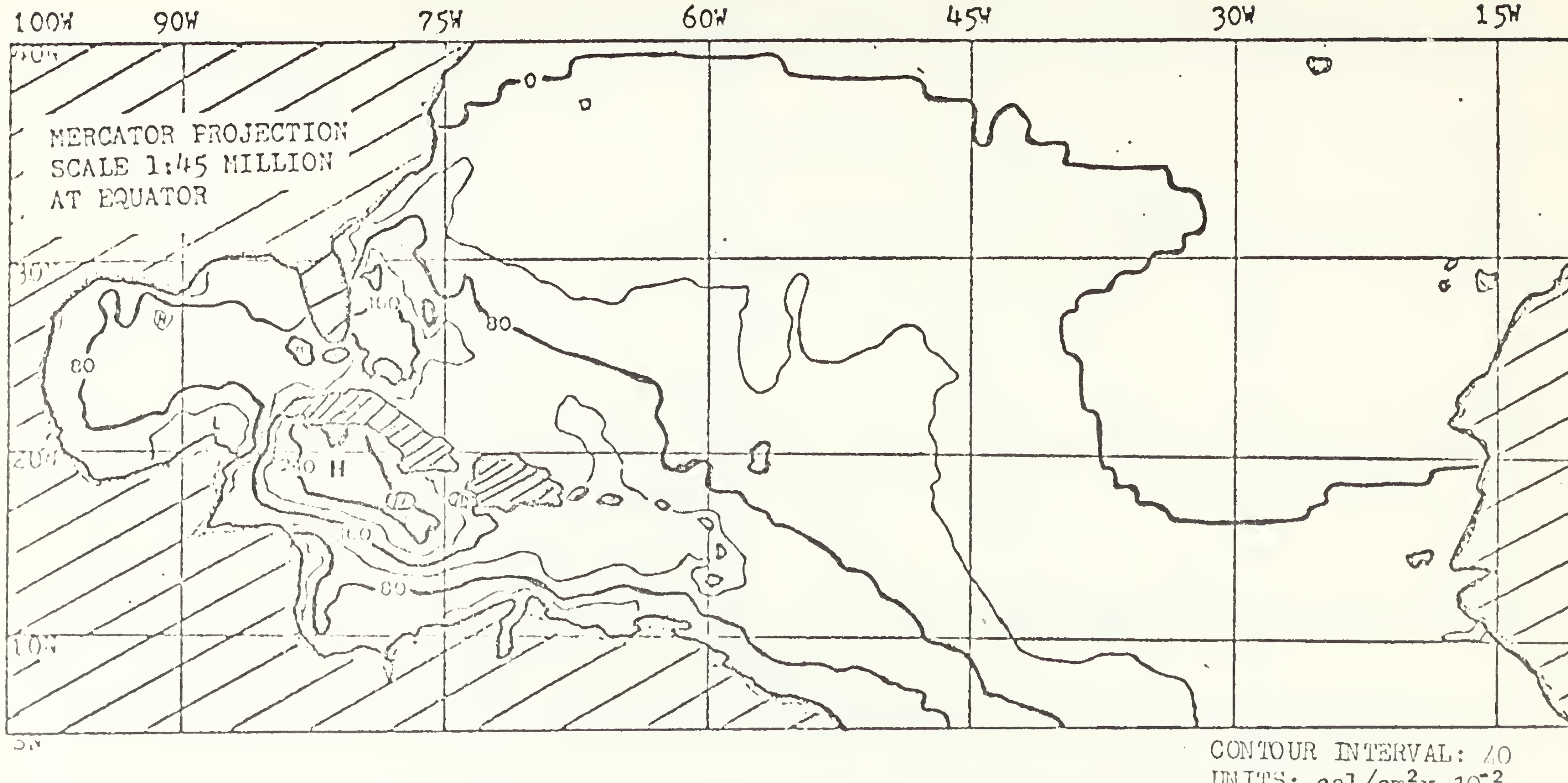
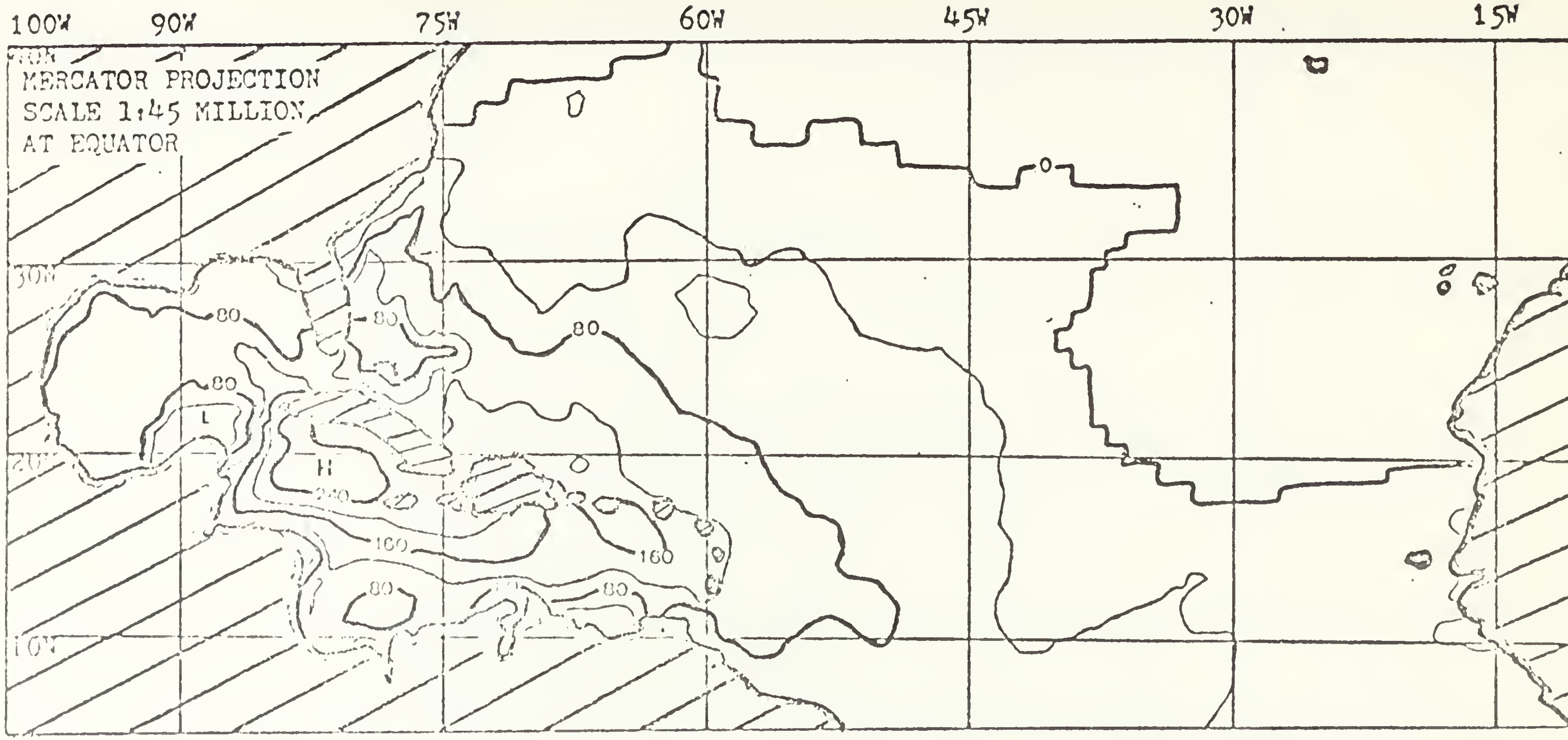


FIGURE (20): AUGUST MEAN HURRICANE HEAT POTENTIAL, NORTH ATLANTIC.



CONTOUR INTERVAL: 40
UNITS: cal/cm^{2}x 10^{-2}

FIGURE (21): SEPTEMBER MEAN HURRICANE HEAT POTENTIAL, NORTH ATLANTIC.

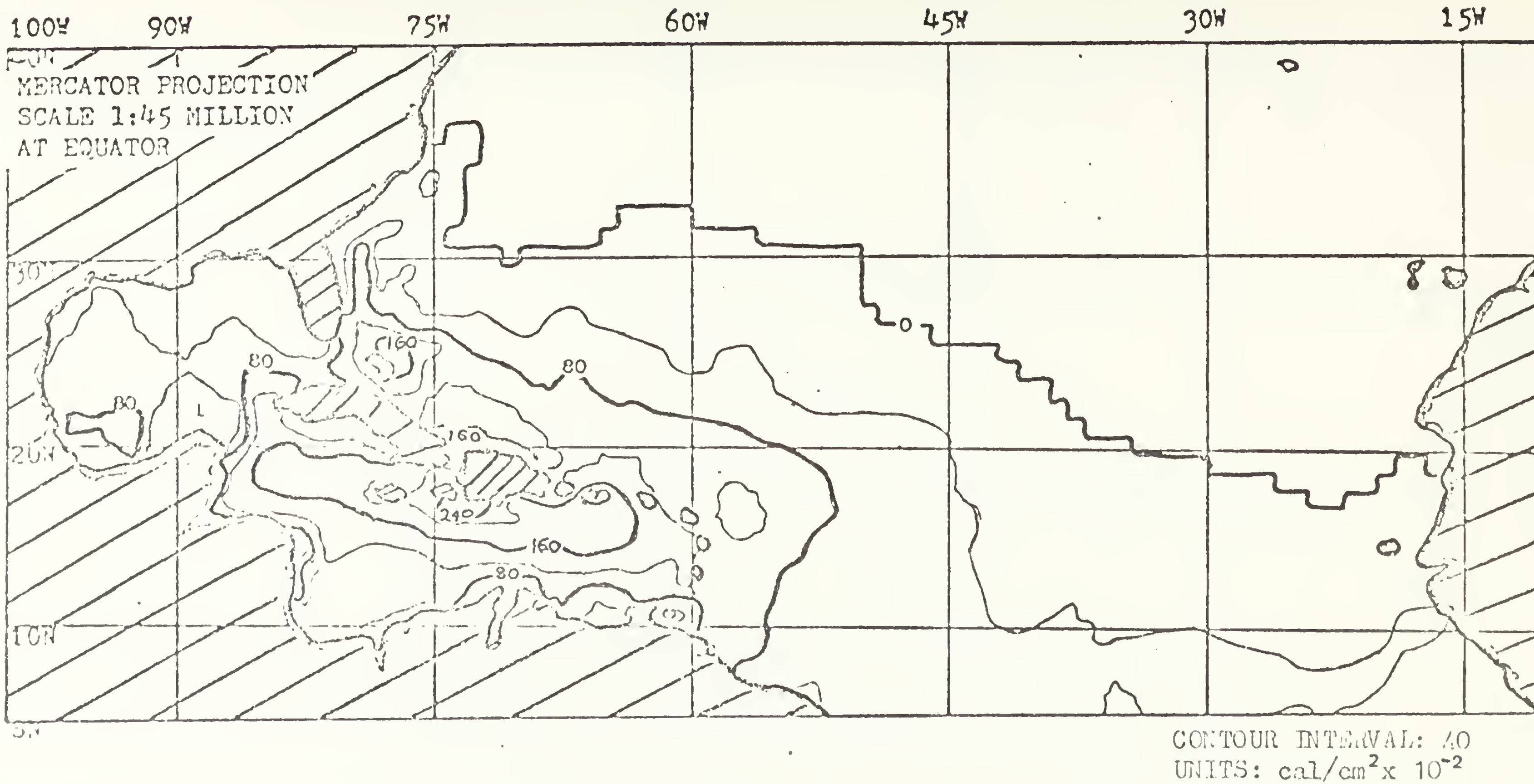
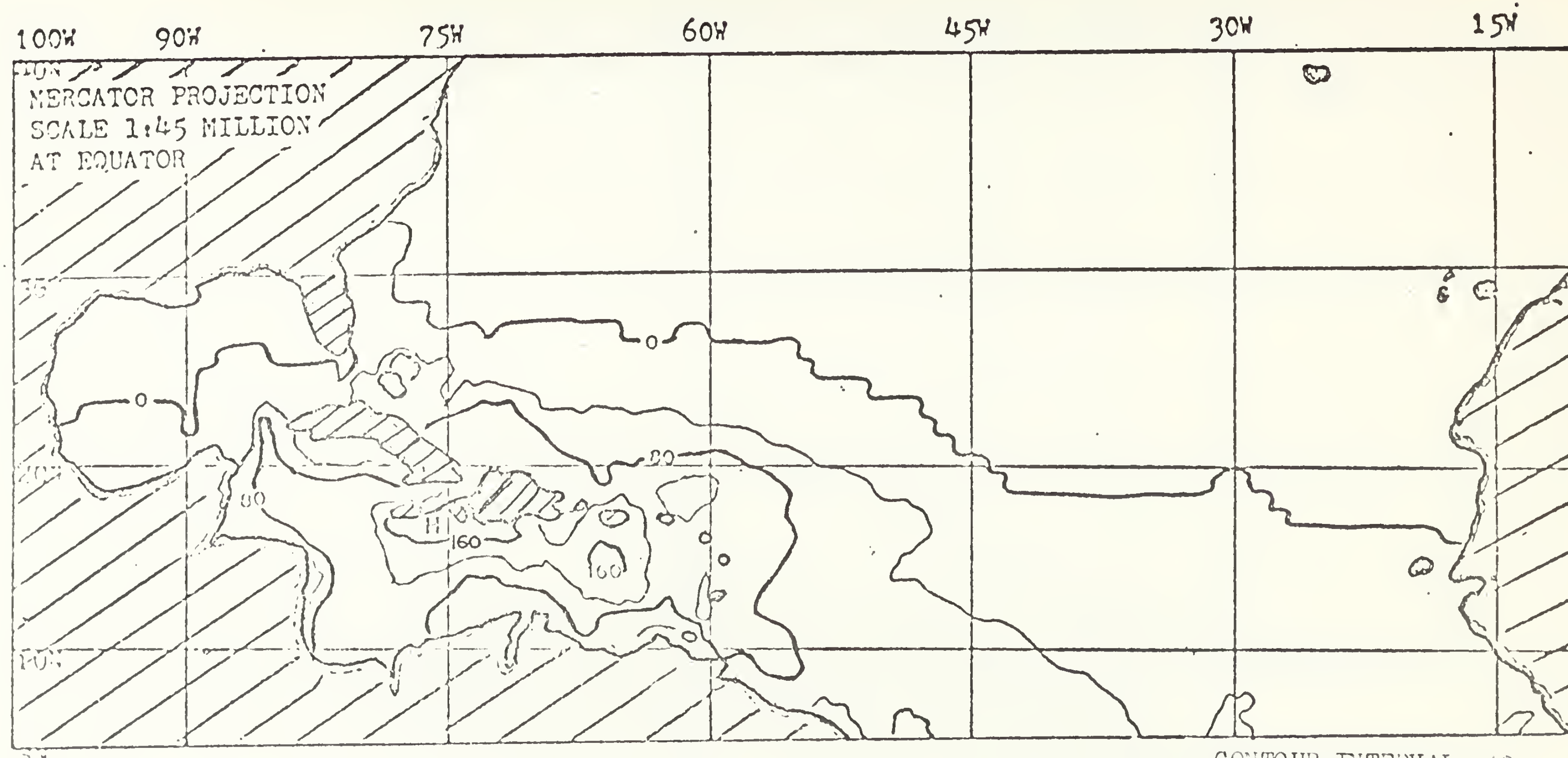


FIGURE (22): OCTOBER MEAN HURRICANE HEAT POTENTIAL, NORTH ATLANTIC.



CONTOUR INTERVAL: 40
UNITS: cal/cm^2 x 10^{-2}

FIGURE (23): NOVEMBER MEAN HURRICANE HEAT POTENTIAL, NORTH ATLANTIC.

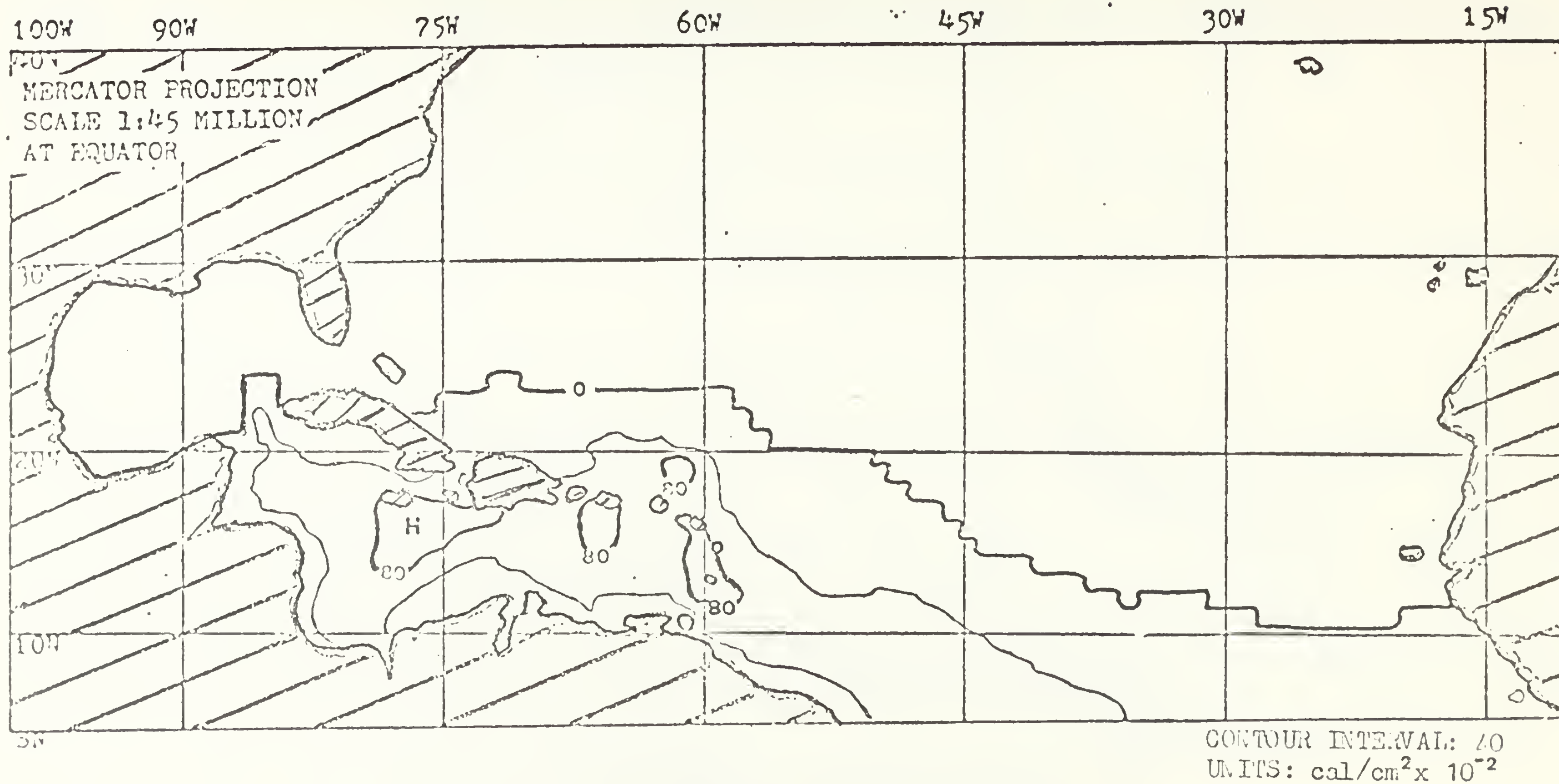
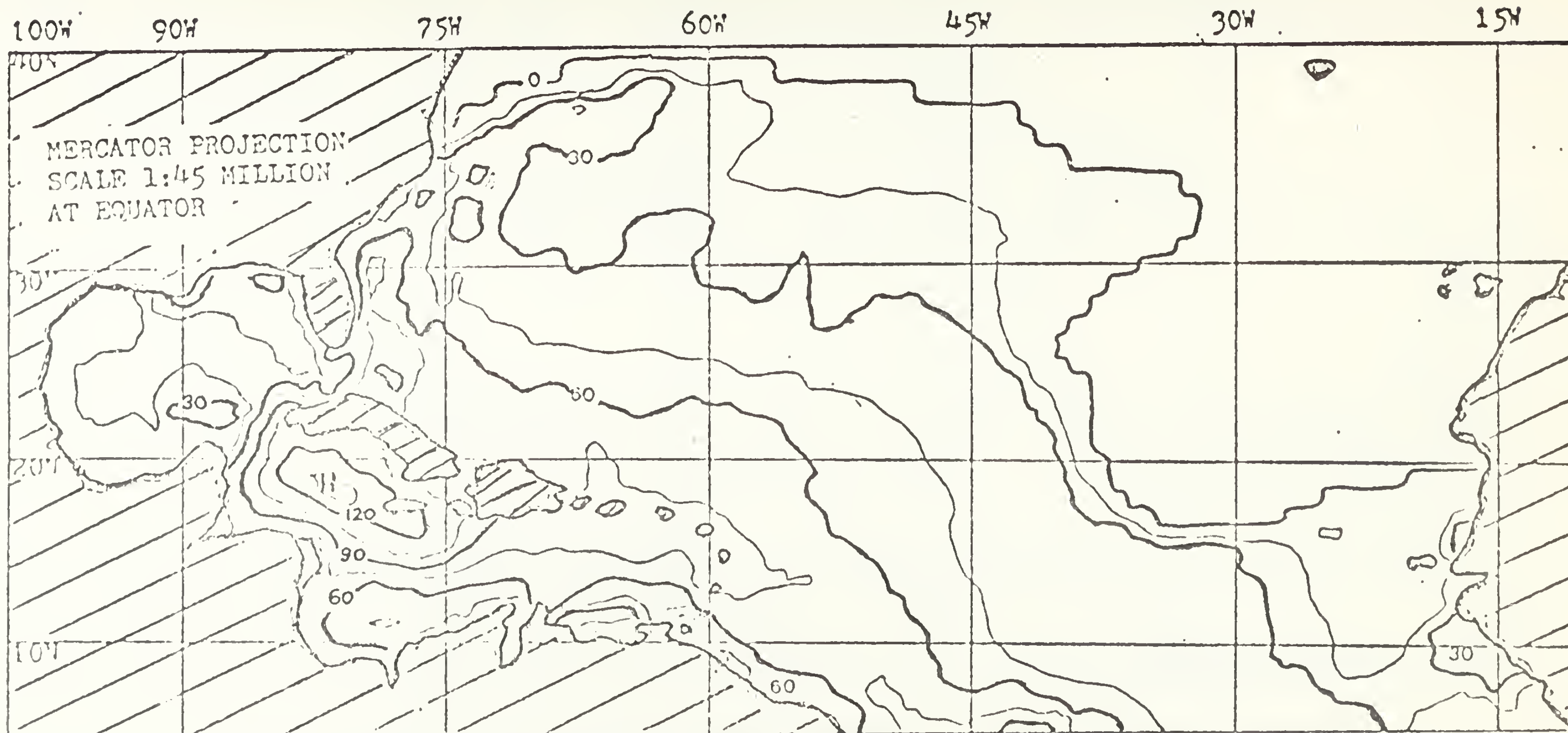


FIGURE (24): DECEMBER MEAN HURRICANE HEAT POTENTIAL, NORTH ATLANTIC.



(CONTOUR INTERVAL: 15 METERS)

FIGURE (25): AUGUST MEAN DEPTH OF 26C ISOTHERM, NORTH ATLANTIC.

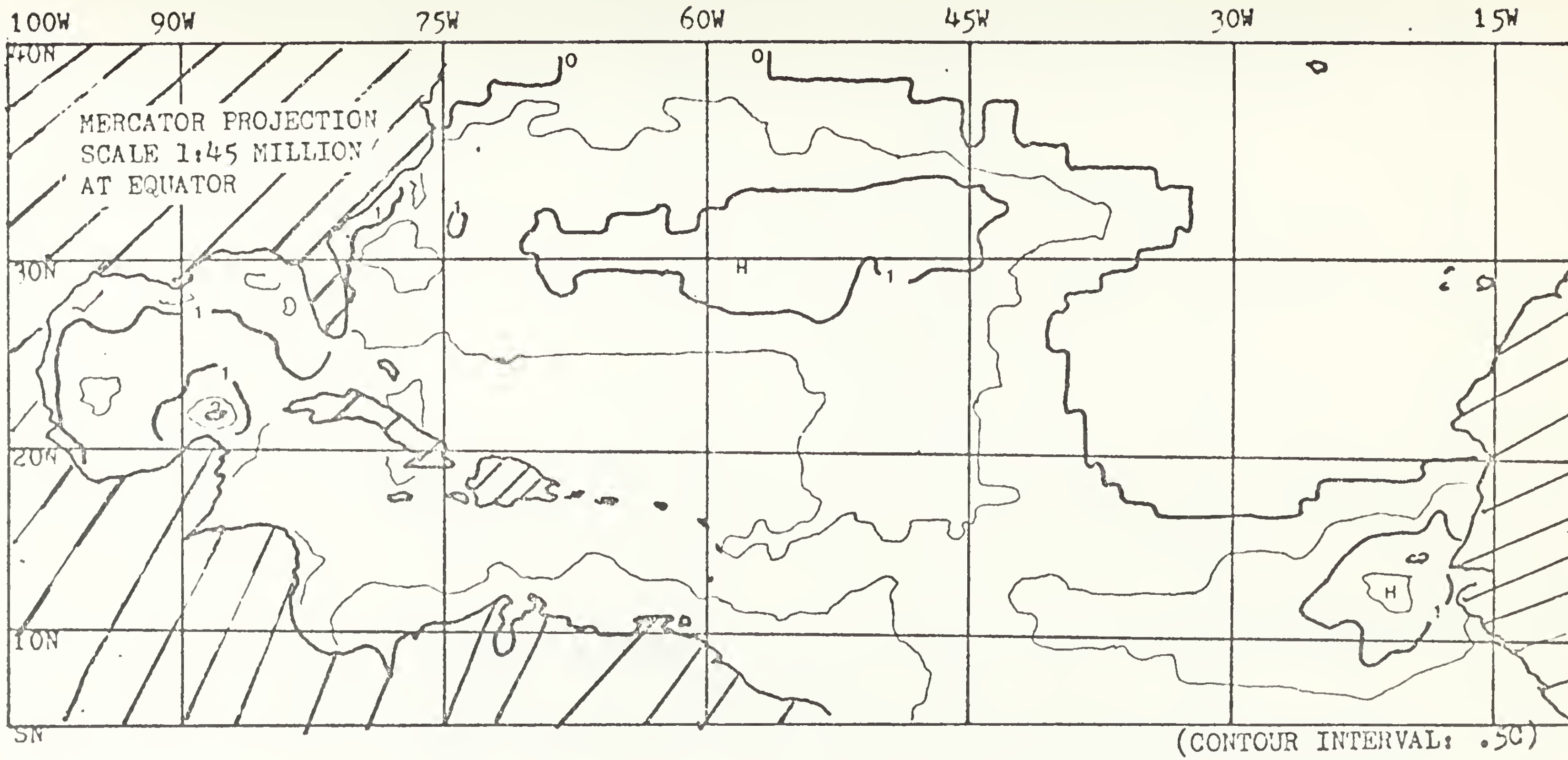


FIGURE (26): AUGUST MEAN SEA SURFACE TEMPERATURE MODIFICATION AFTER PASSAGE OF A HURRICANE, 06 HOUR EFFECT, NORTH ATLANTIC.

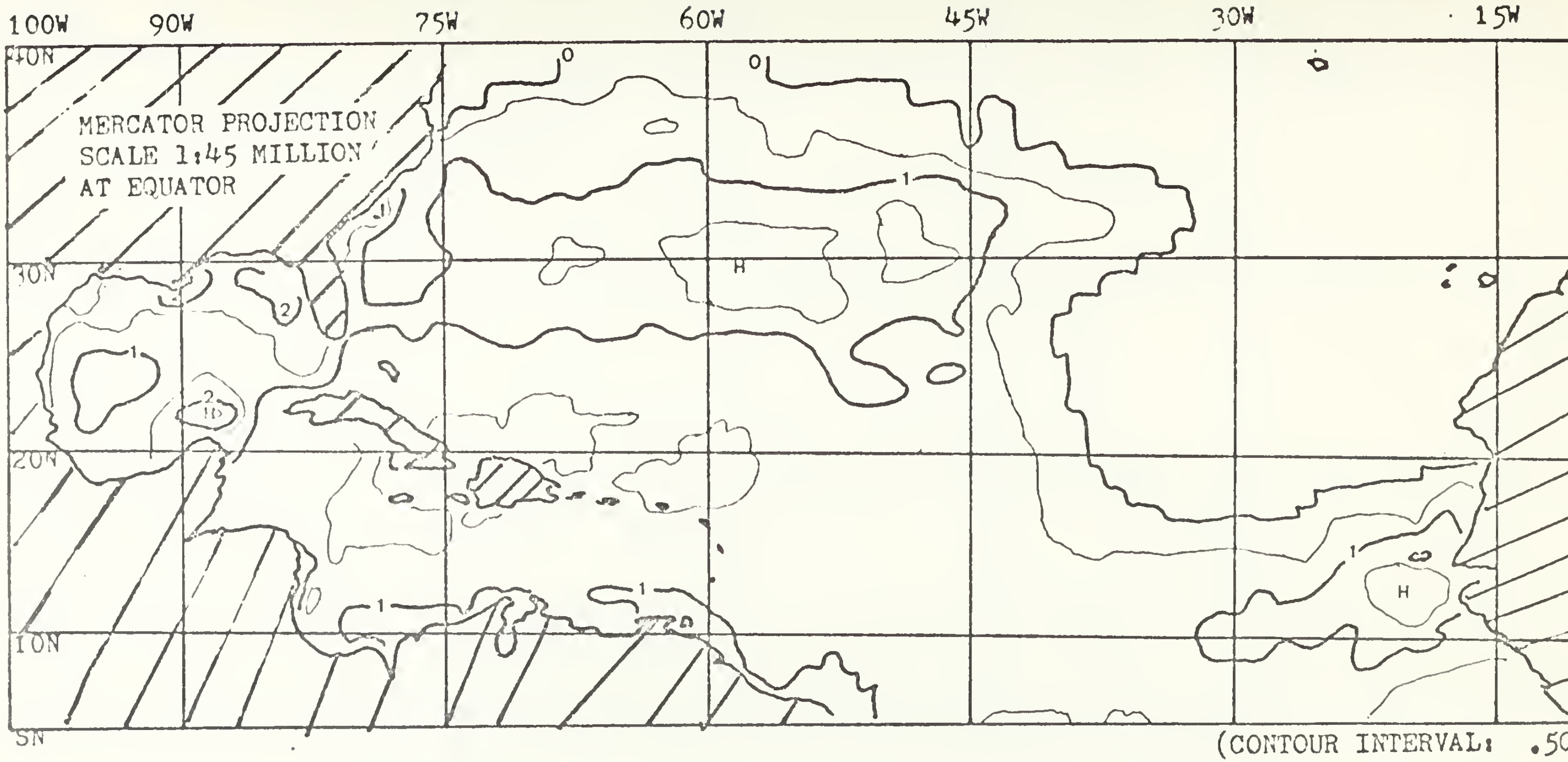


FIGURE (27): AUGUST MEAN SEA SURFACE TEMPERATURE MODIFICATION AFTER PASSAGE OF A HURRICANE, 12 HOUR EFFECT, NORTH ATLANTIC.

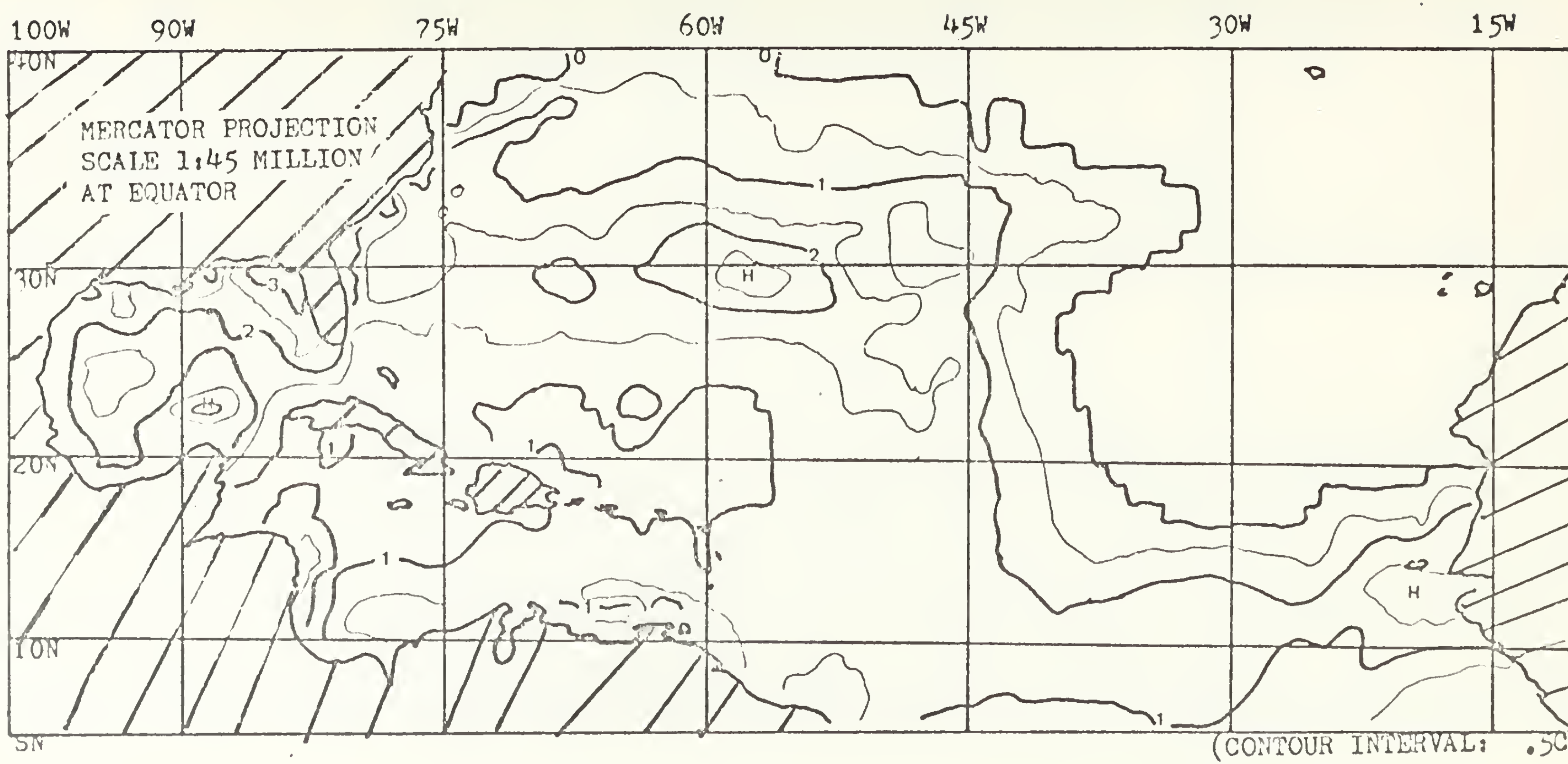
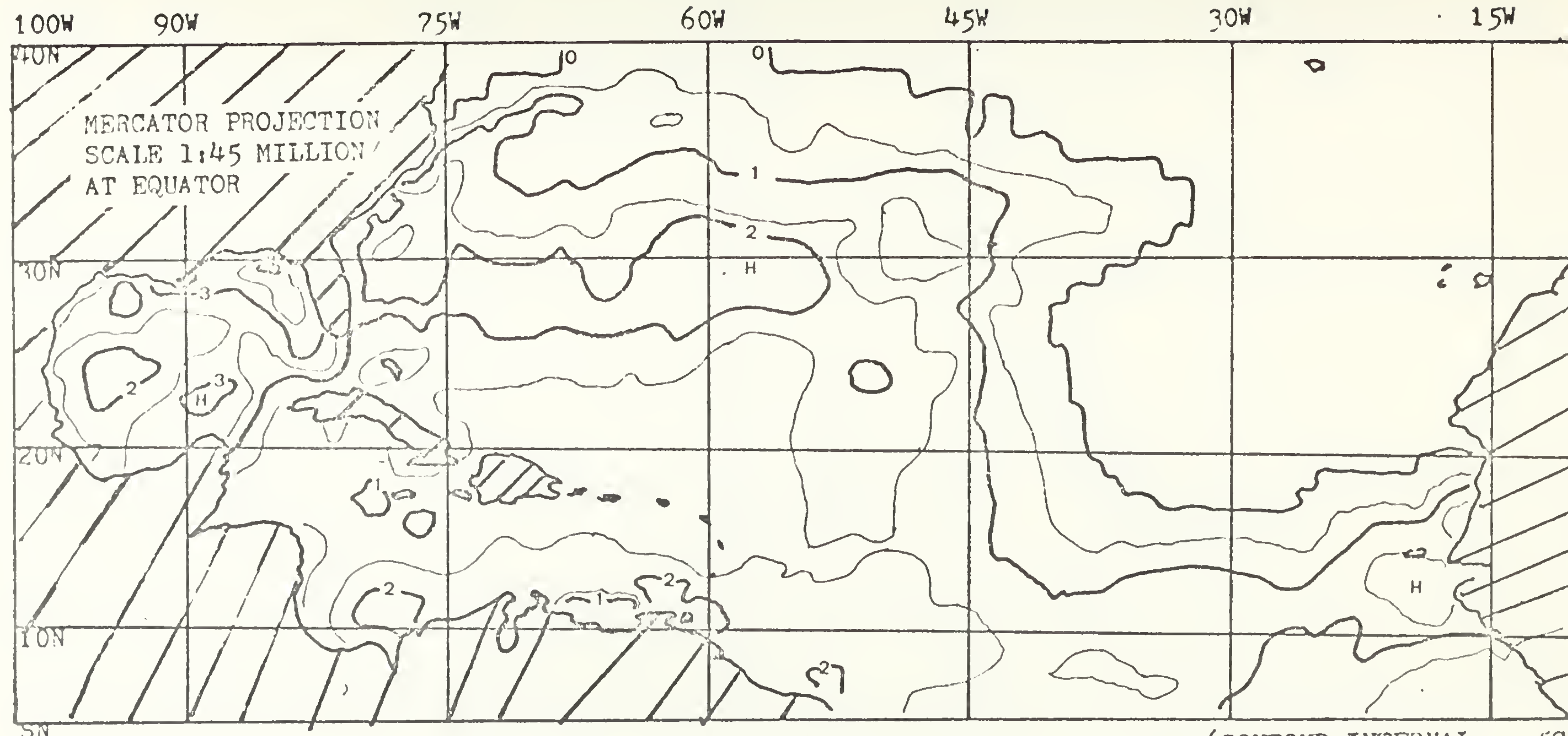
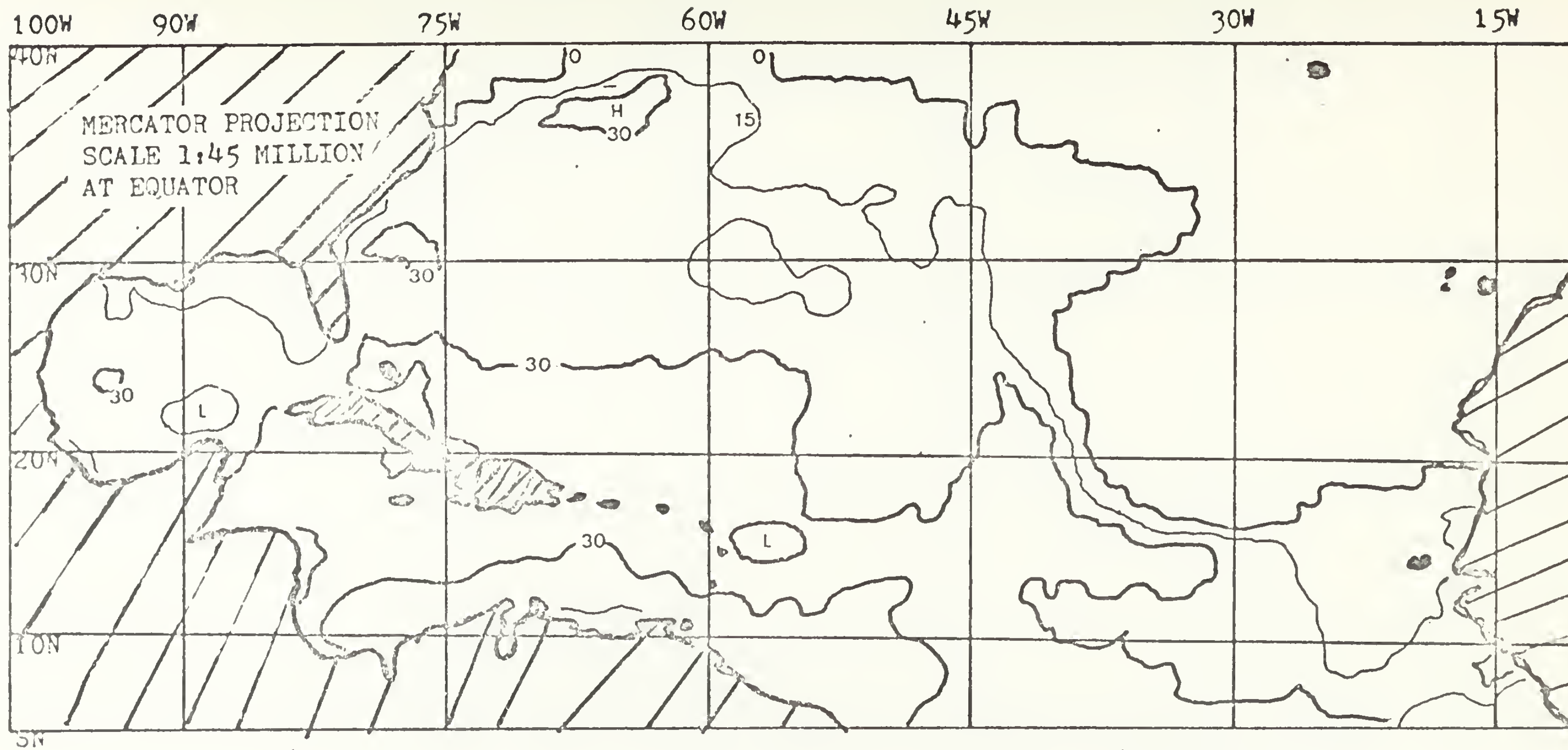


FIGURE (28): AUGUST MEAN SEA SURFACE TEMPERATURE MODIFICATION AFTER PASSAGE OF A HURRICANE, 24 HOUR EFFECT, NORTH ATLANTIC.



(CONTOUR INTERVAL: .5C)

FIGURE (29): AUGUST MEAN SEA SURFACE TEMPERATURE MODIFICATION AFTER PASSAGE OF A HURRICANE, 36 HOUR EFFECT, NORTH ATLANTIC.



(CONTOUR INTERVAL: 15 METERS)

FIGURE (30): AUGUST MEAN CONVECTIVE LAYER DEPTH AFTER PASSAGE OF A HURRICANE, 06 HOUR EFFECT, NORTH ATLANTIC.

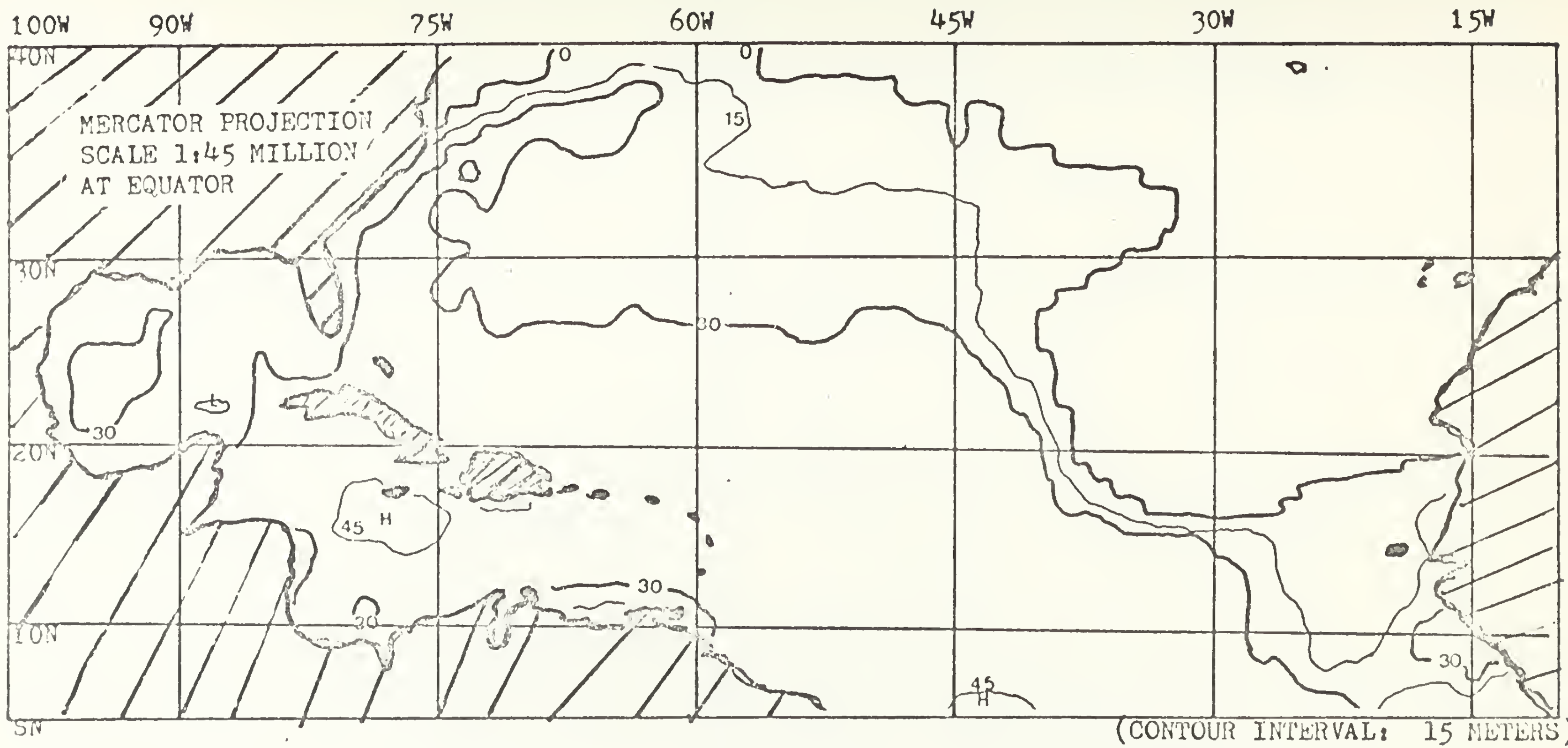


FIGURE (31): AUGUST MEAN CONVECTIVE LAYER DEPTH AFTER PASSAGE OF A HURRICANE, 12 HOUR EFFECT, NORTH ATLANTIC.

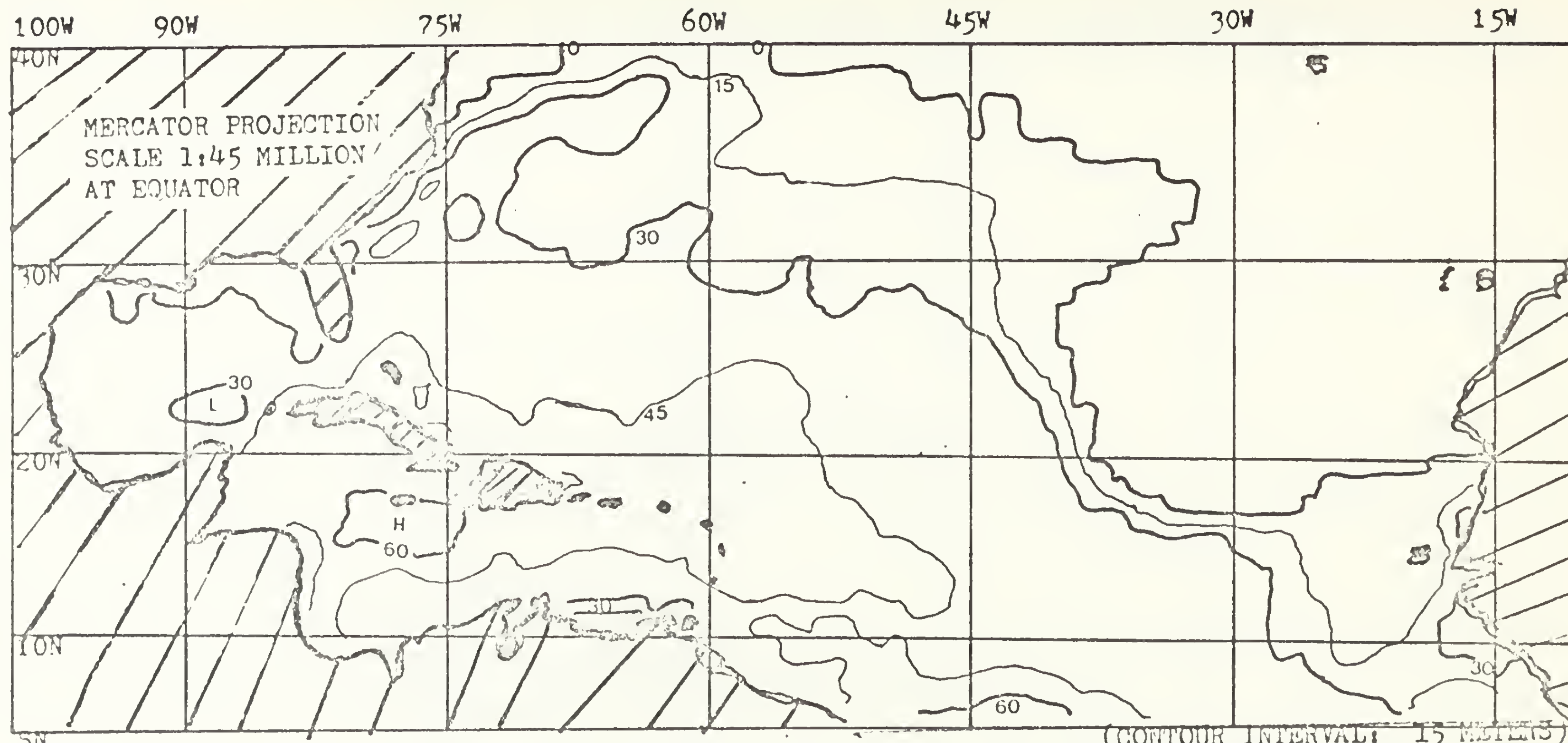


FIGURE (32): AUGUST MEAN CONVECTIVE LAYER DEPTH AFTER PASSAGE OF A HURRICANE, 24 HOUR EFFECT, NORTH ATLANTIC.

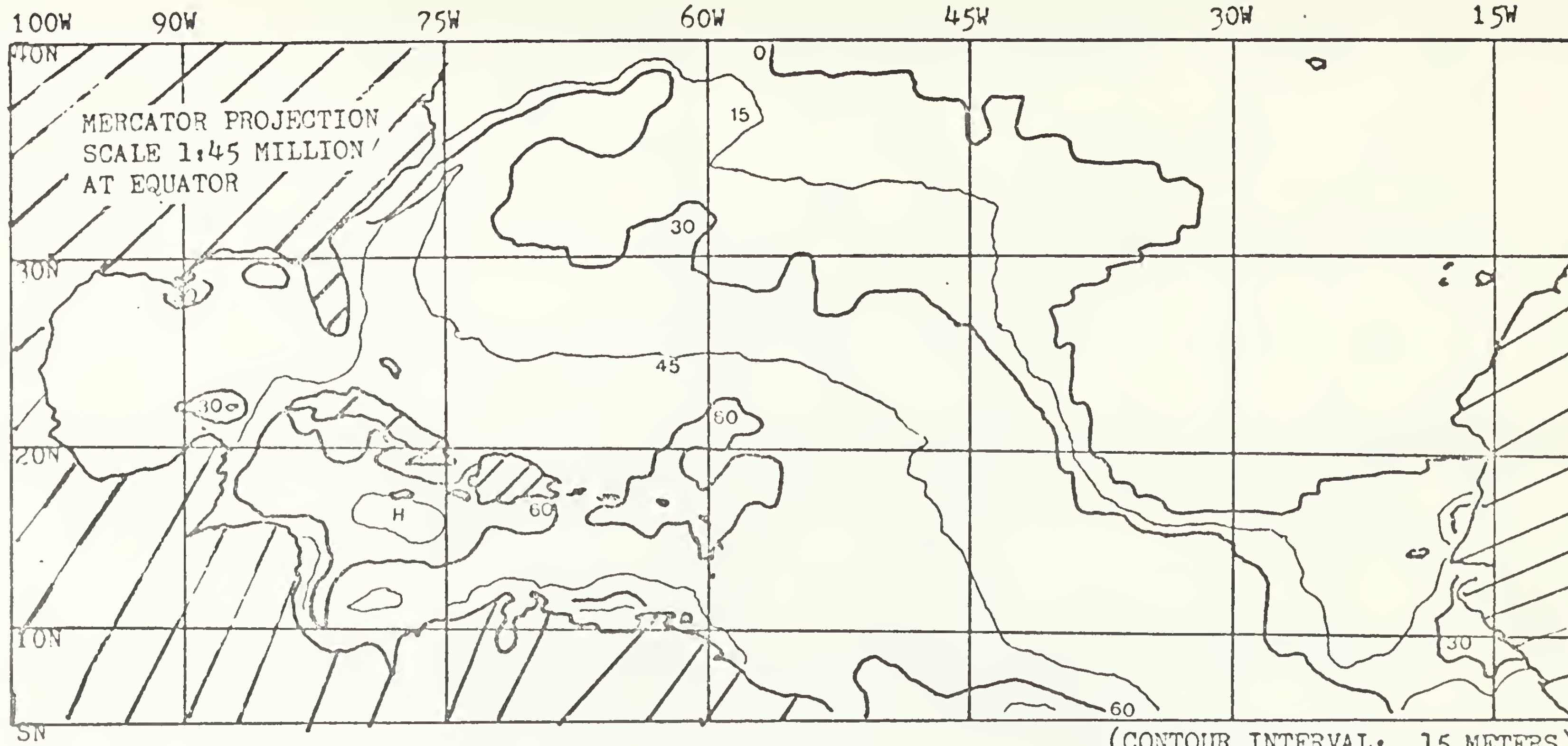


FIGURE (33): AUGUST MEAN CONVECTIVE LAYER DEPTH AFTER PASSAGE OF A HURRICANE, 36 HOUR EFFECT, NORTH ATLANTIC.

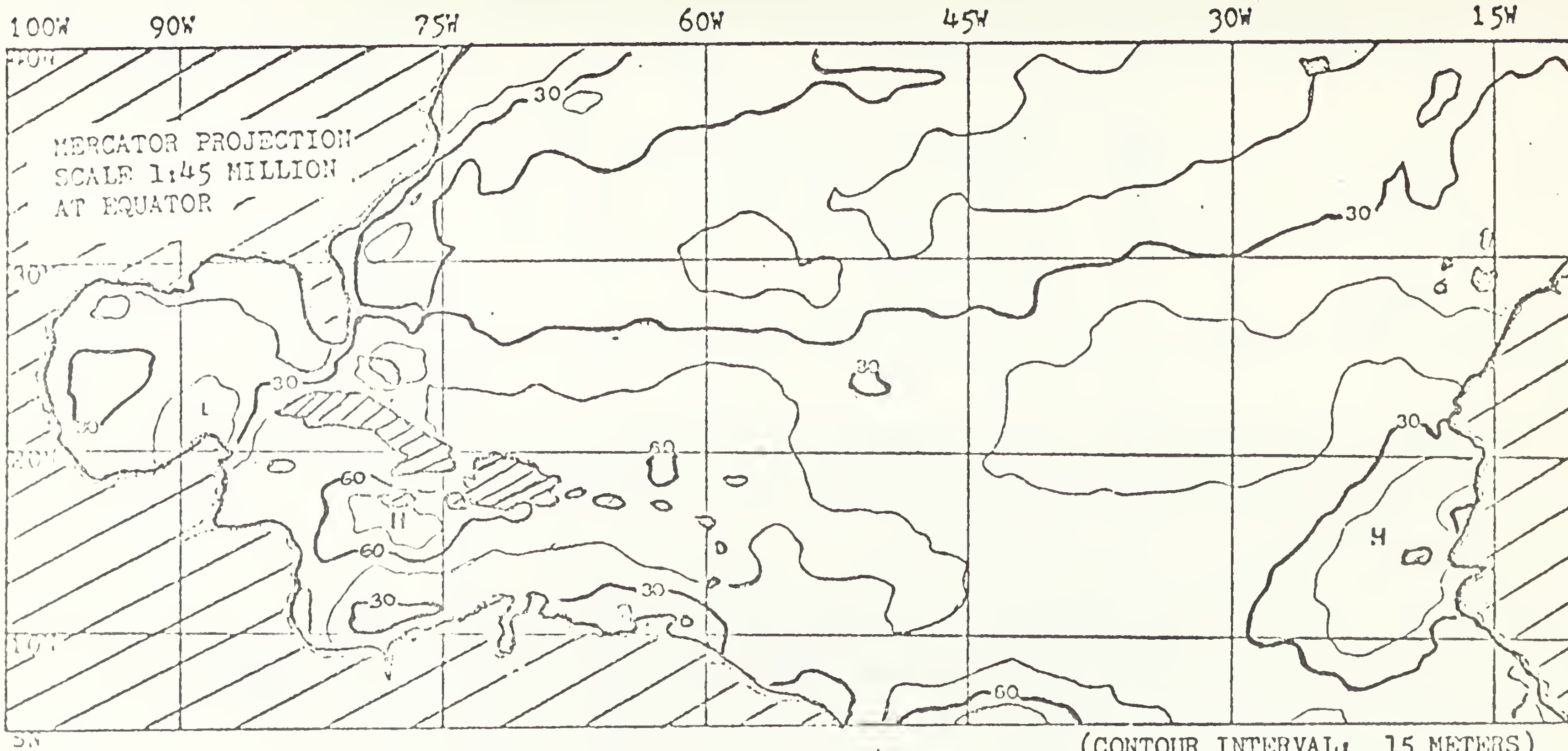
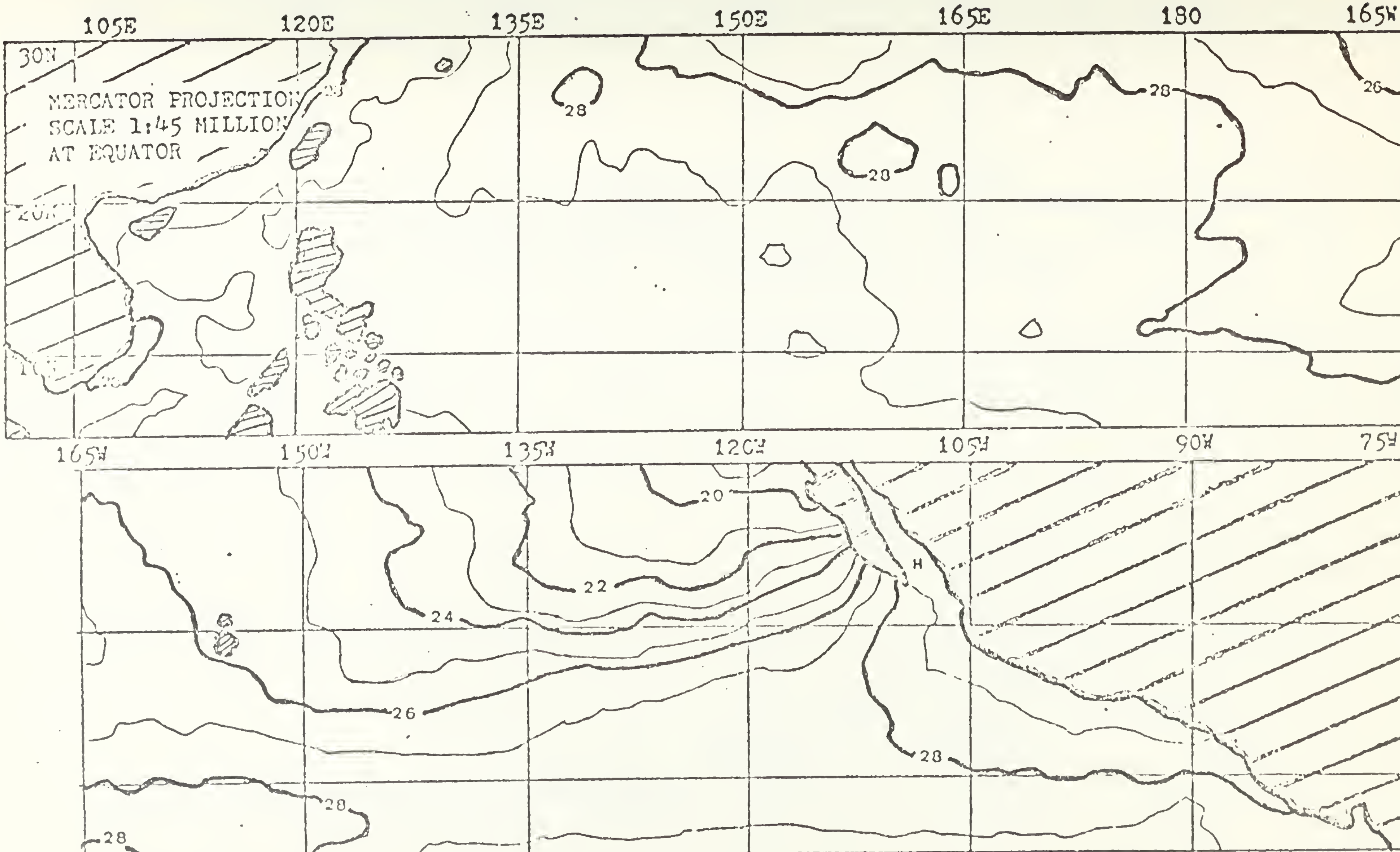


FIGURE (34): AUGUST MEAN LAYER DEPTH, NORTH ATLANTIC.



(CONTOUR INTERVAL: 1C)

FIGURE (35): AUGUST MEAN SEA SURFACE TEMPERATURE, NORTH PACIFIC.

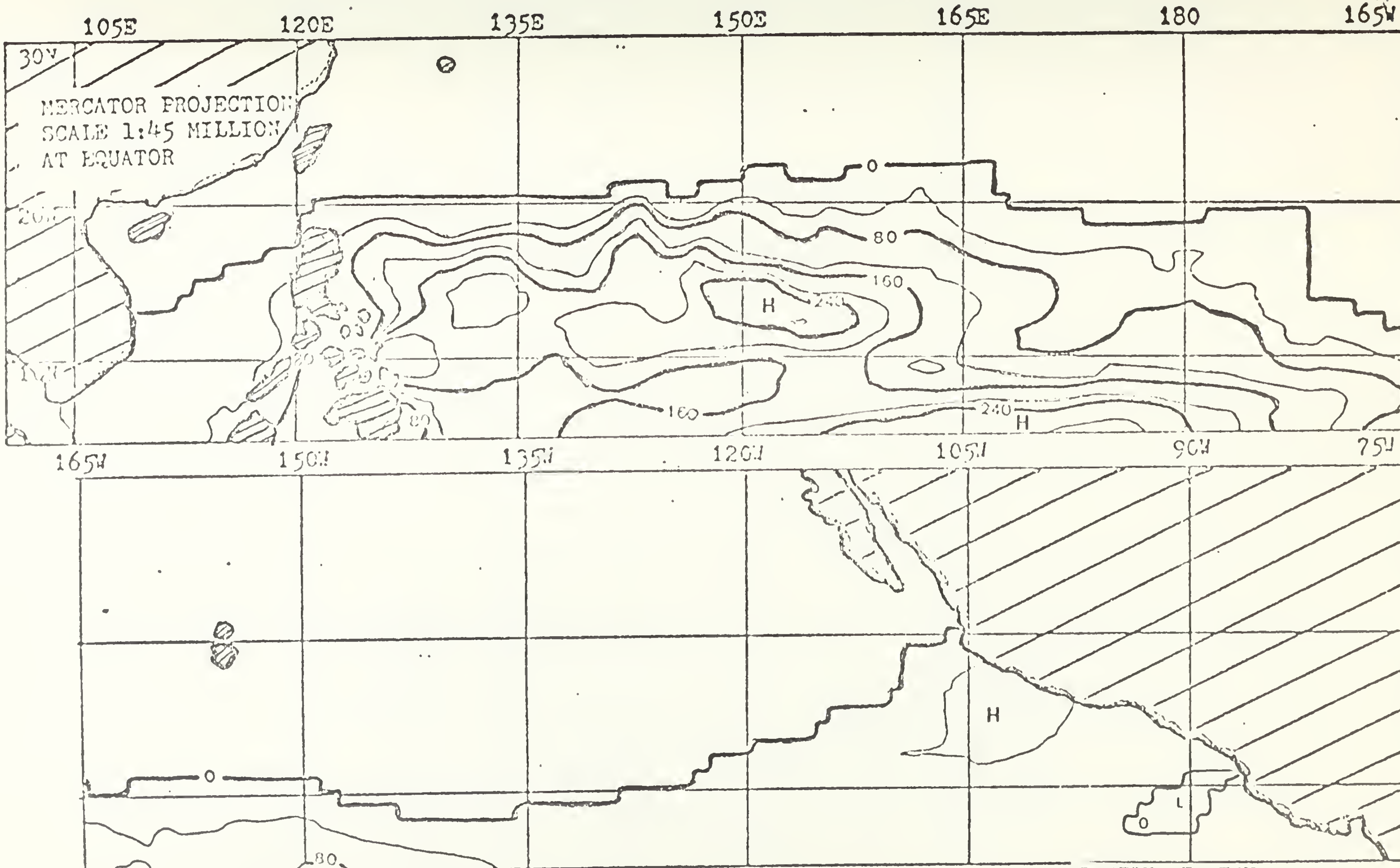


FIGURE (36): JANUARY MEAN HURRICANE HEAT POTENTIAL, NORTH PACIFIC.

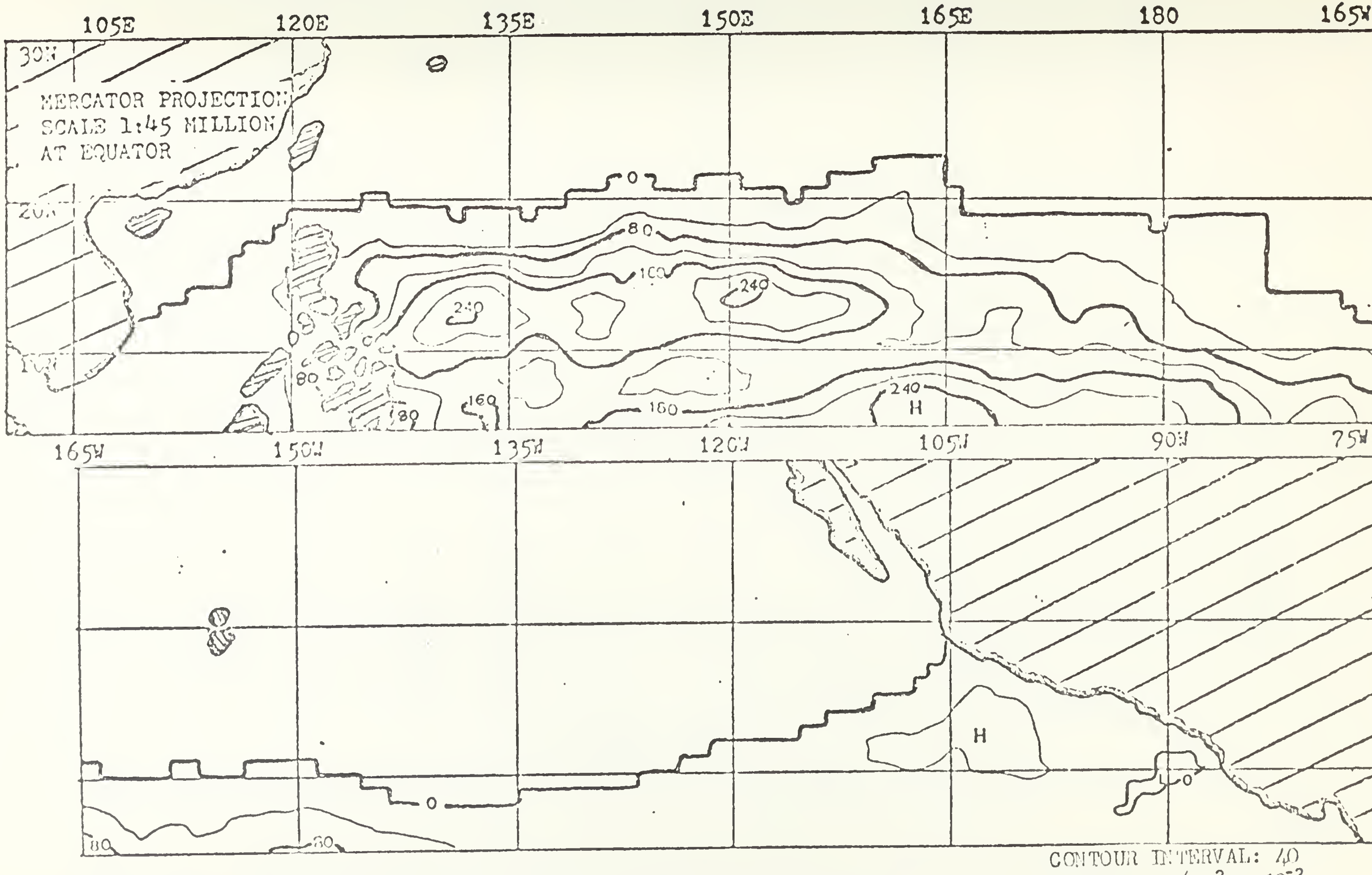
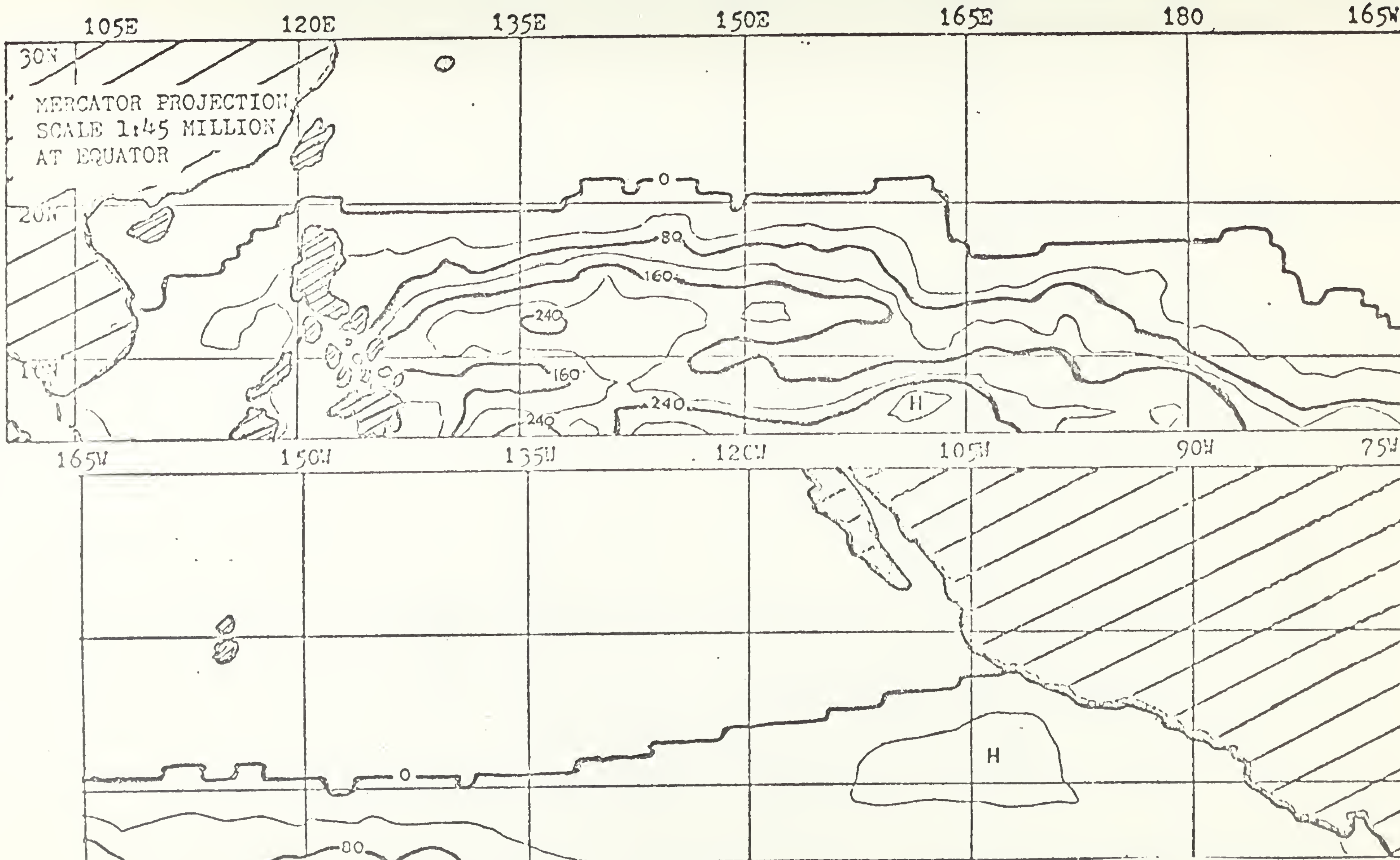
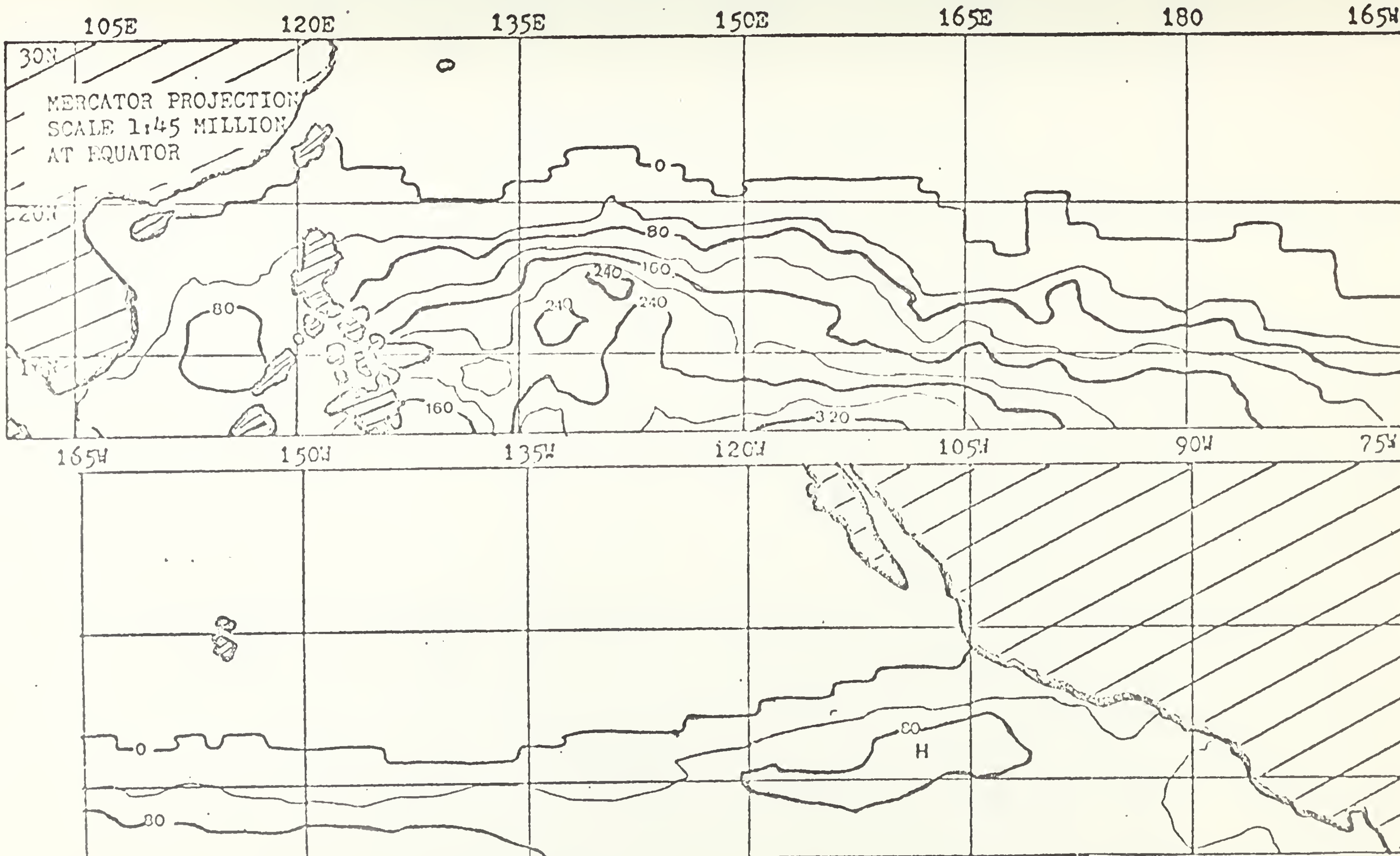


FIGURE (37): FEBRUARY MEAN HURRICANE HEAT POTENTIAL, NORTH PACIFIC.



CONTOUR INTERVAL: 40
UNITS: cal/cm^{2}x 10^{-2}

FIGURE (38): MARCH MEAN HURRICANE HEAT POTENTIAL, NORTH PACIFIC.



CONTOUR INTERVAL: 40
UNITS: $cal/cm^2 \times 10^{-2}$

FIGURE (39): APRIL MEAN HURRICANE HEAT POTENTIAL, NORTH PACIFIC.

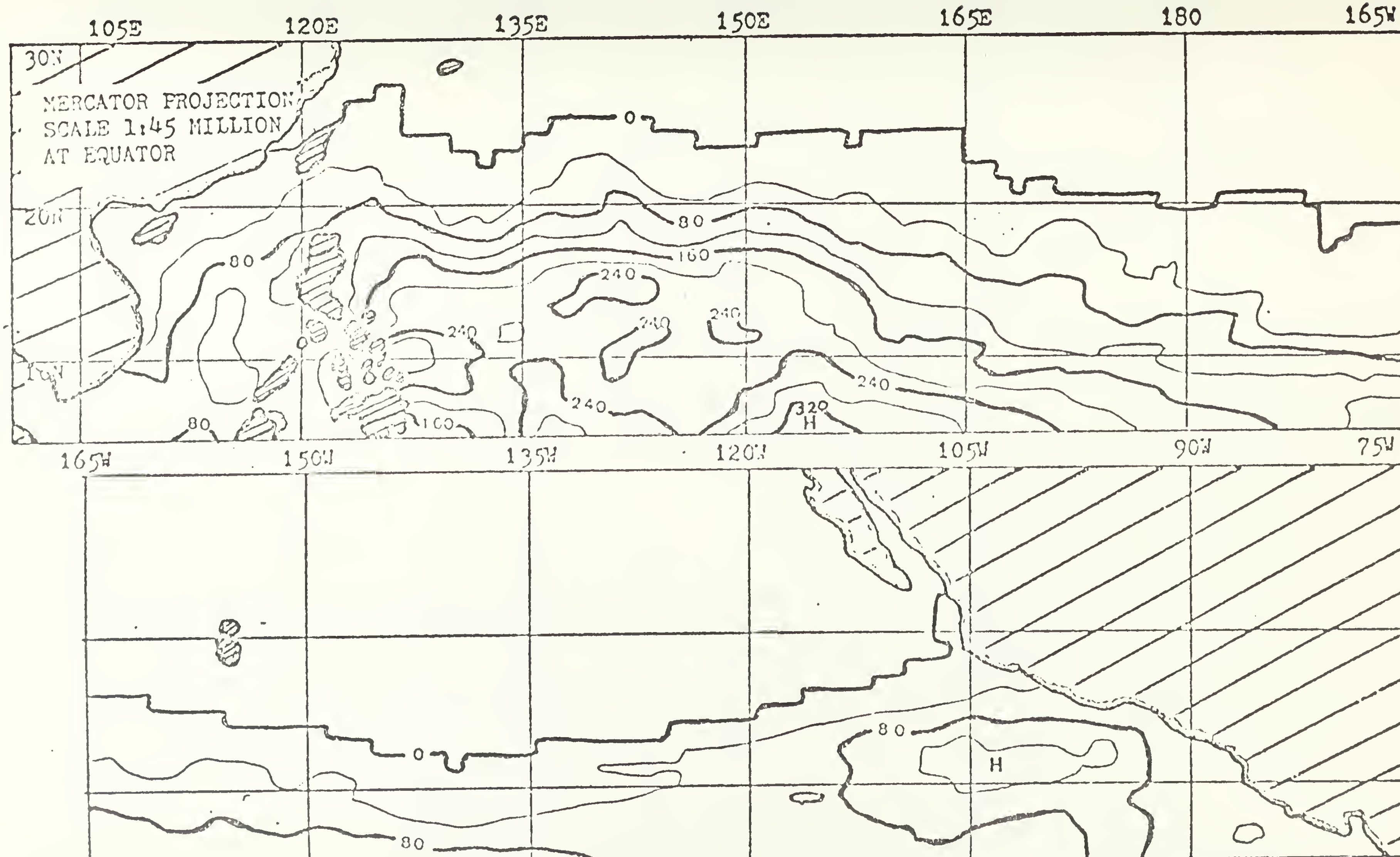


FIGURE (40): MAY MEAN HURRICANE HEAT POTENTIAL, NORTH PACIFIC.

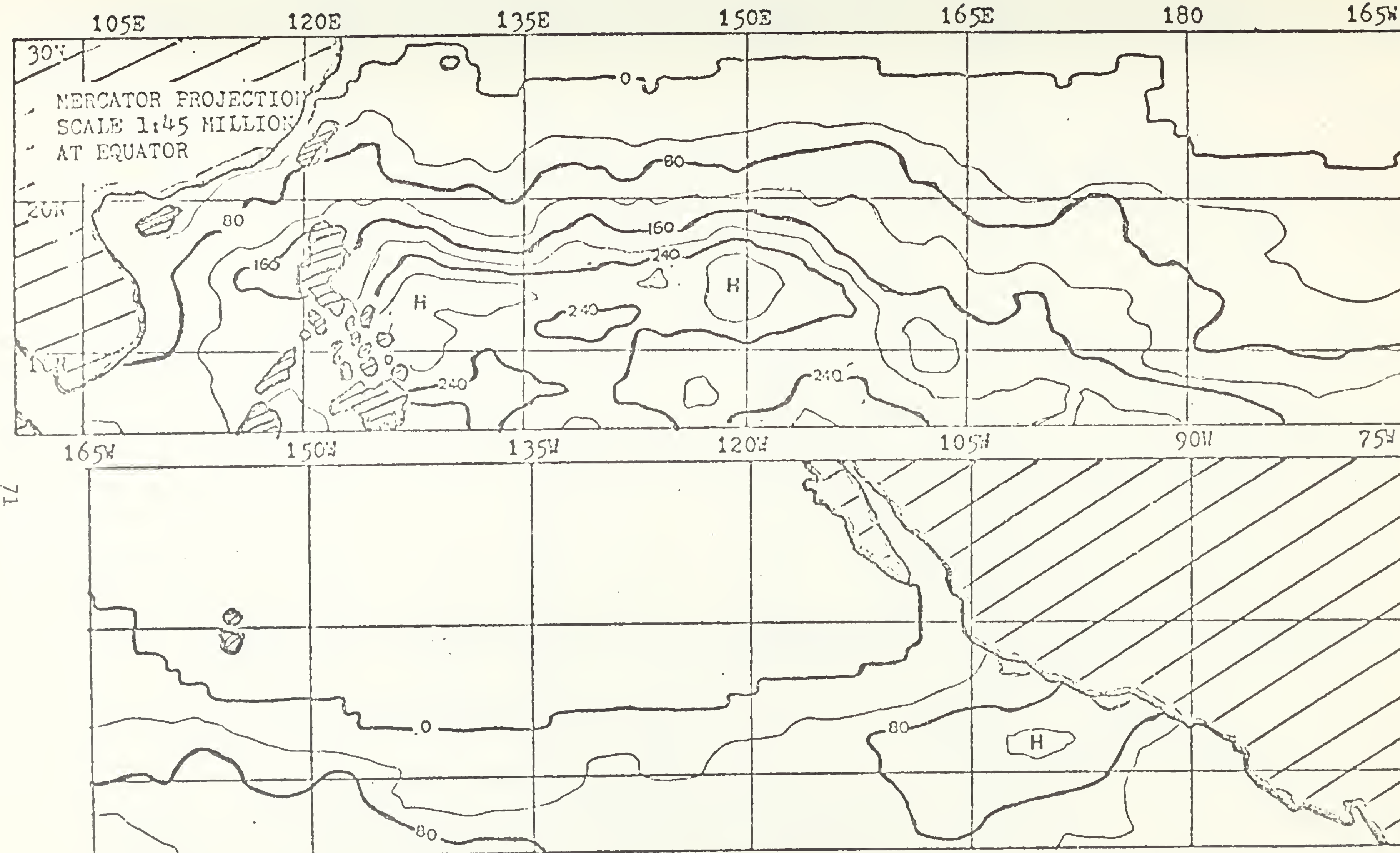


FIGURE (41): JUNE MEAN HURRICANE HEAT POTENTIAL, NORTH PACIFIC.

CONTOUR INTERVAL: 40
UNITS: cal/cm^{2}x 10^{-2}

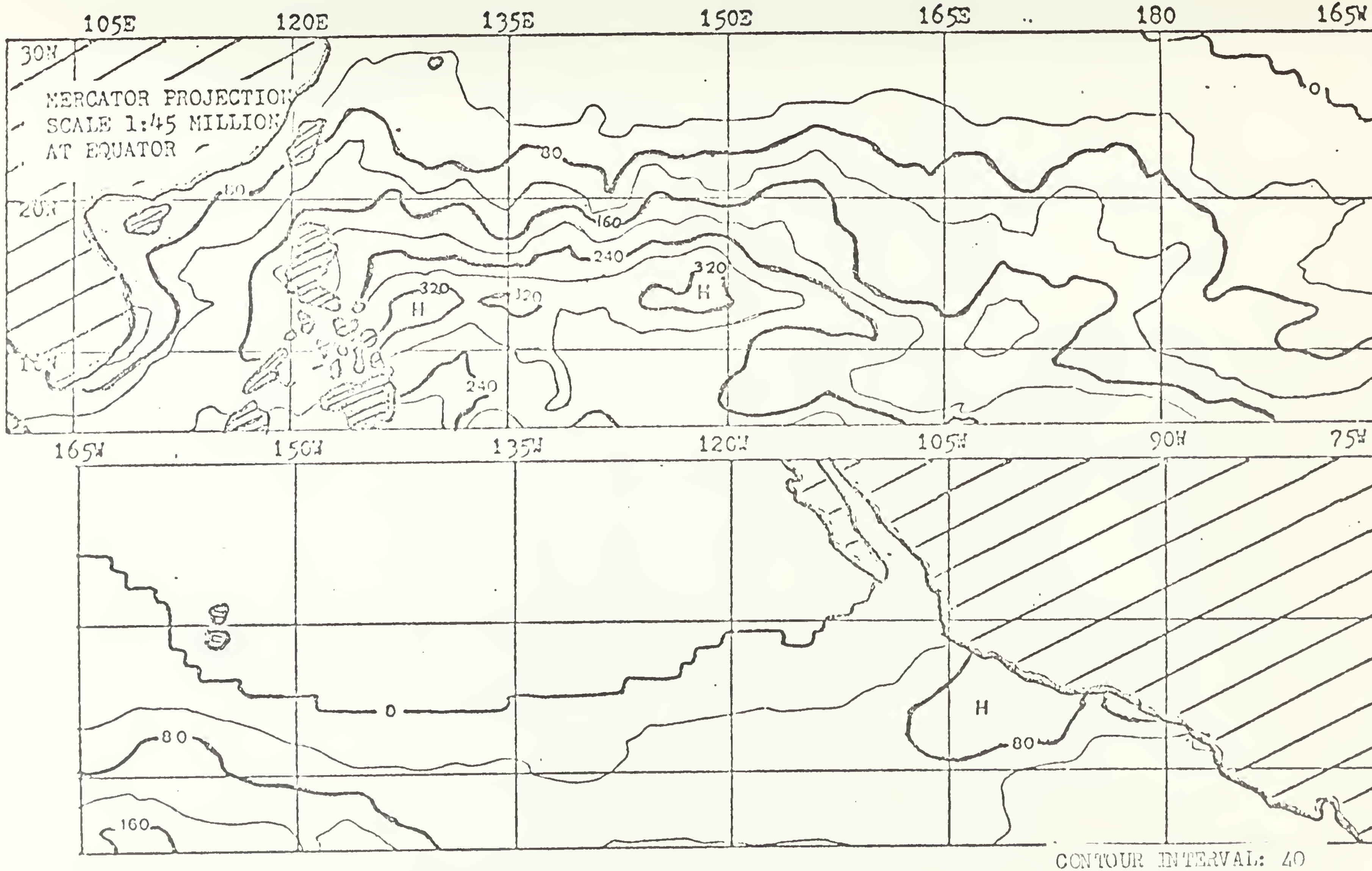
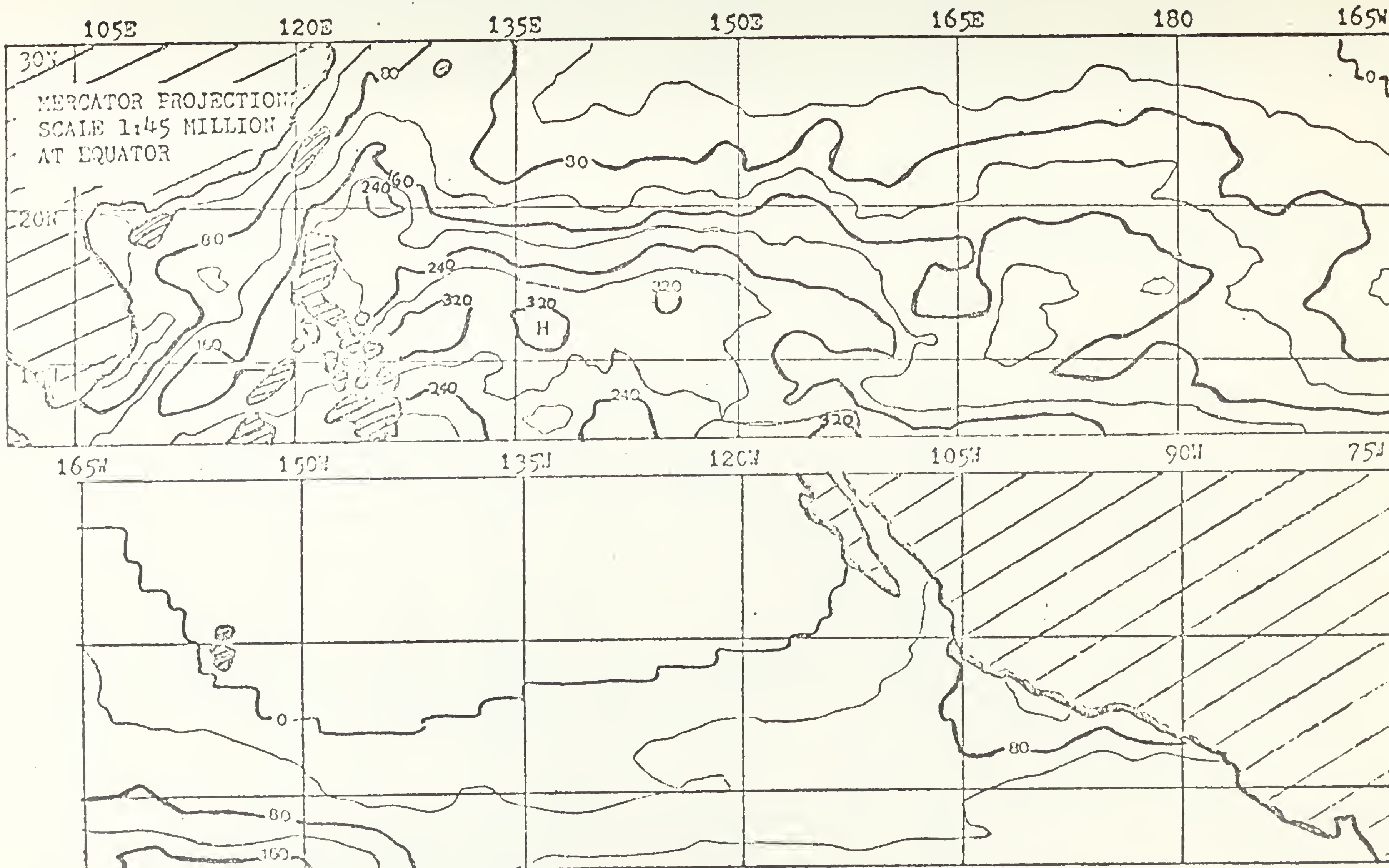


FIGURE (42): JULY MEAN HURRICANE HEAT POTENTIAL, NORTH PACIFIC.



CONTOUR INTERVAL: 40
UNITS: $cal/cm^2 \times 10^{-2}$

FIGURE (43): AUGUST MEAN HURRICANE HEAT POTENTIAL, NORTH PACIFIC.

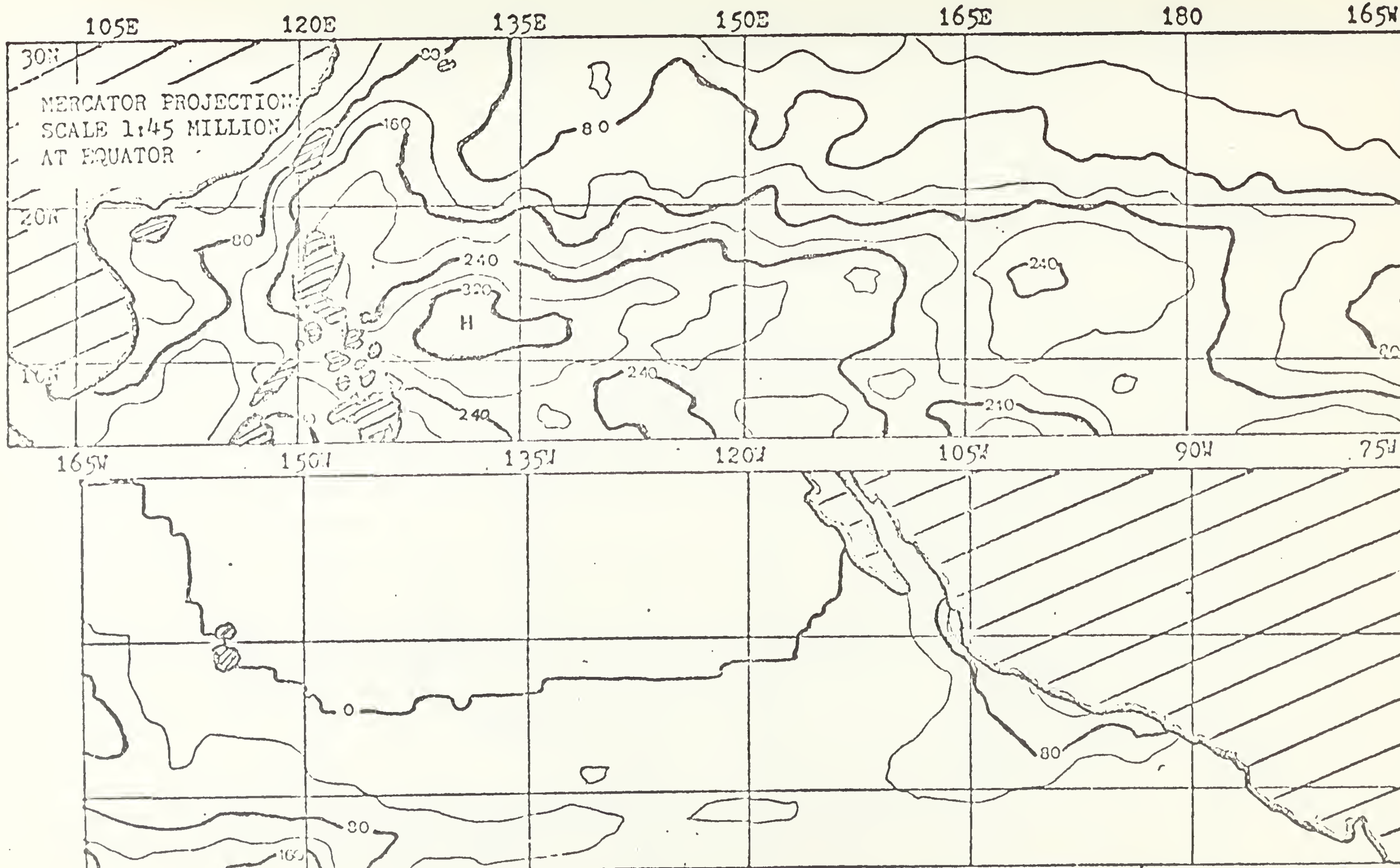


FIGURE (44): SEPTEMBER MEAN HURRICANE HEAT POTENTIAL, NORTH PACIFIC.

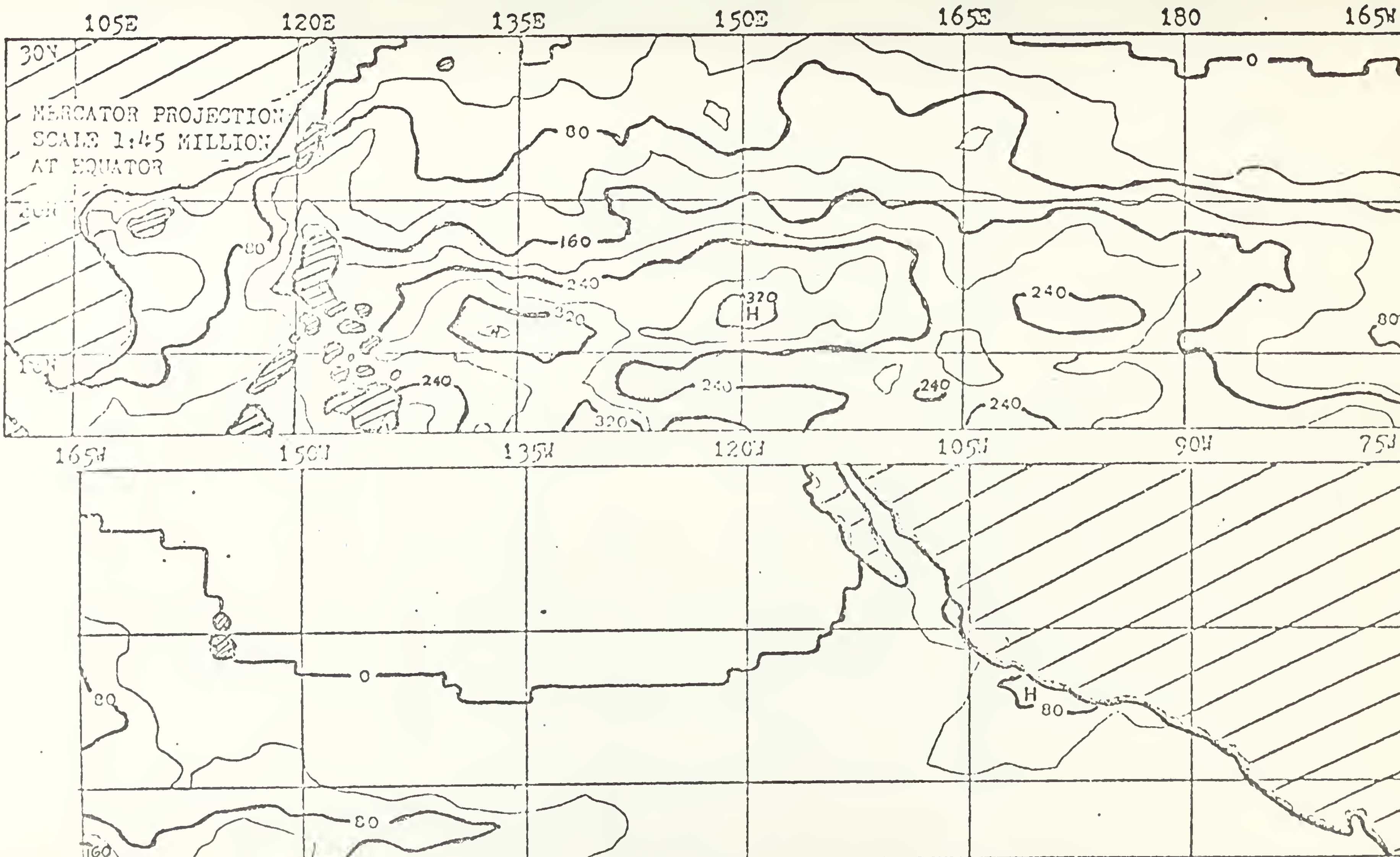
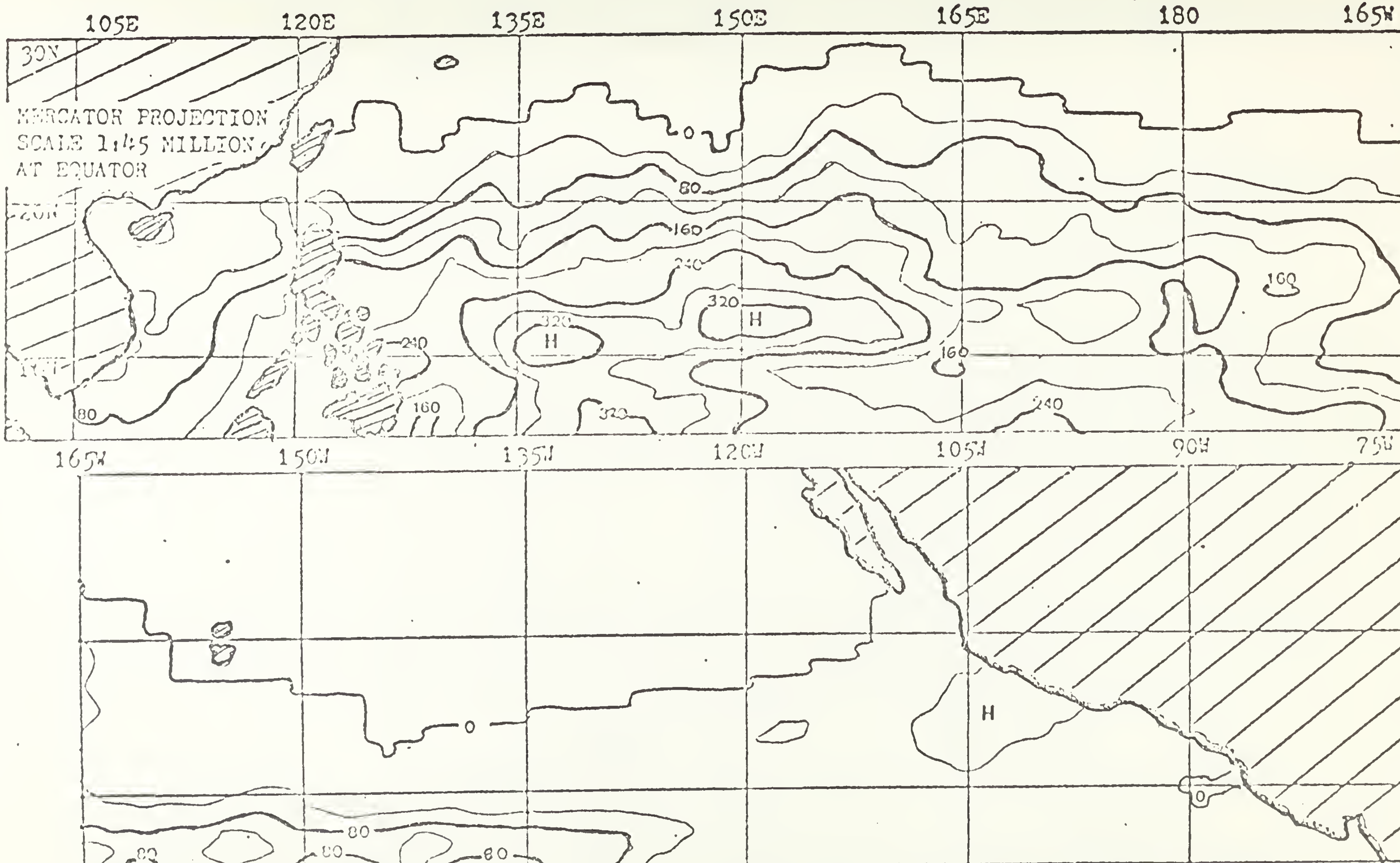


FIGURE (45): OCTOBER MEAN HURRICANE HEAT POTENTIAL, NORTH PACIFIC.



CONTOUR INTERVAL: 40
UNITS: $cal/cm^2 \times 10^{-2}$

FIGURE (46): NOVEMBER MEAN HURRICANE HEAT POTENTIAL, NORTH PACIFIC.

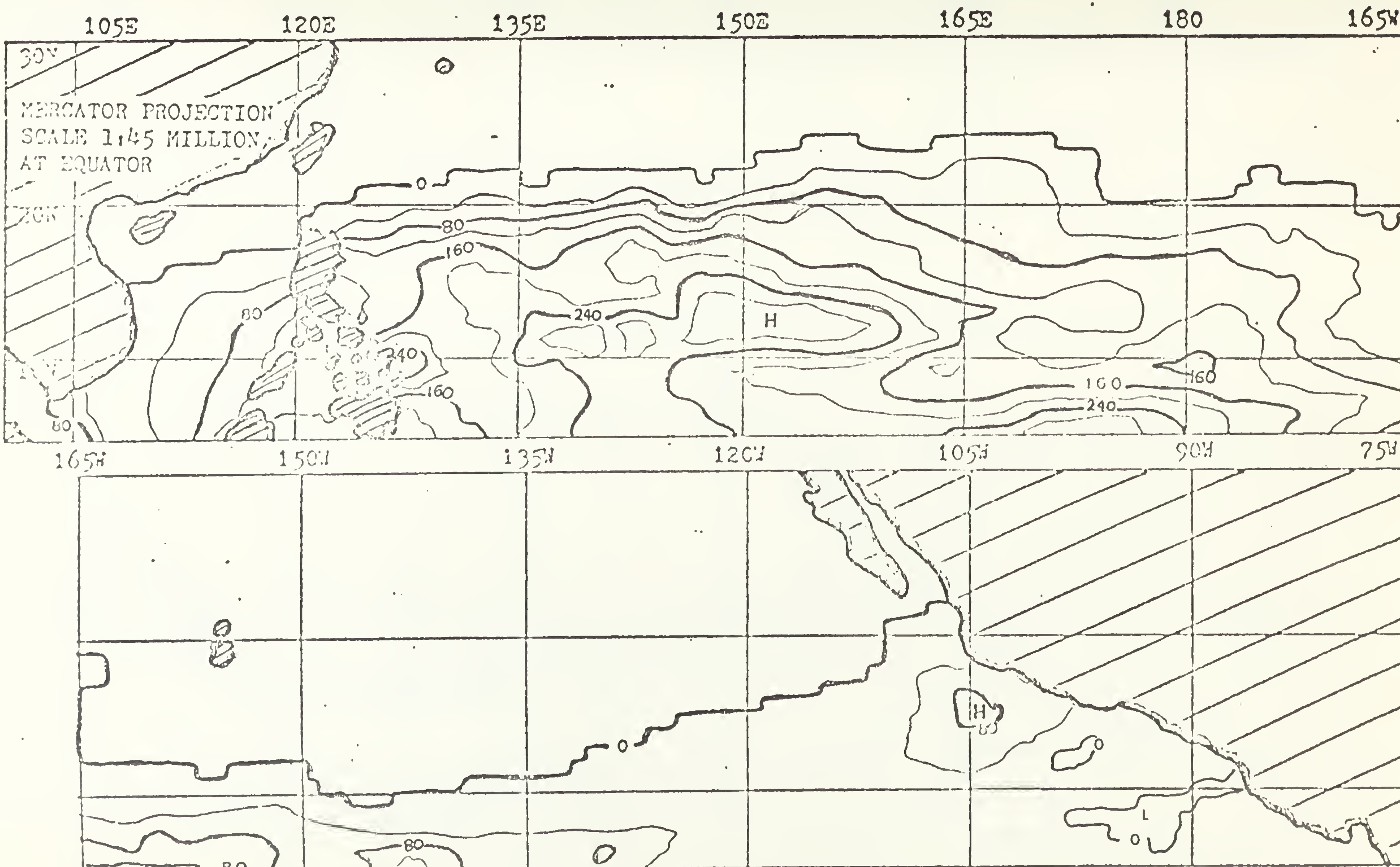
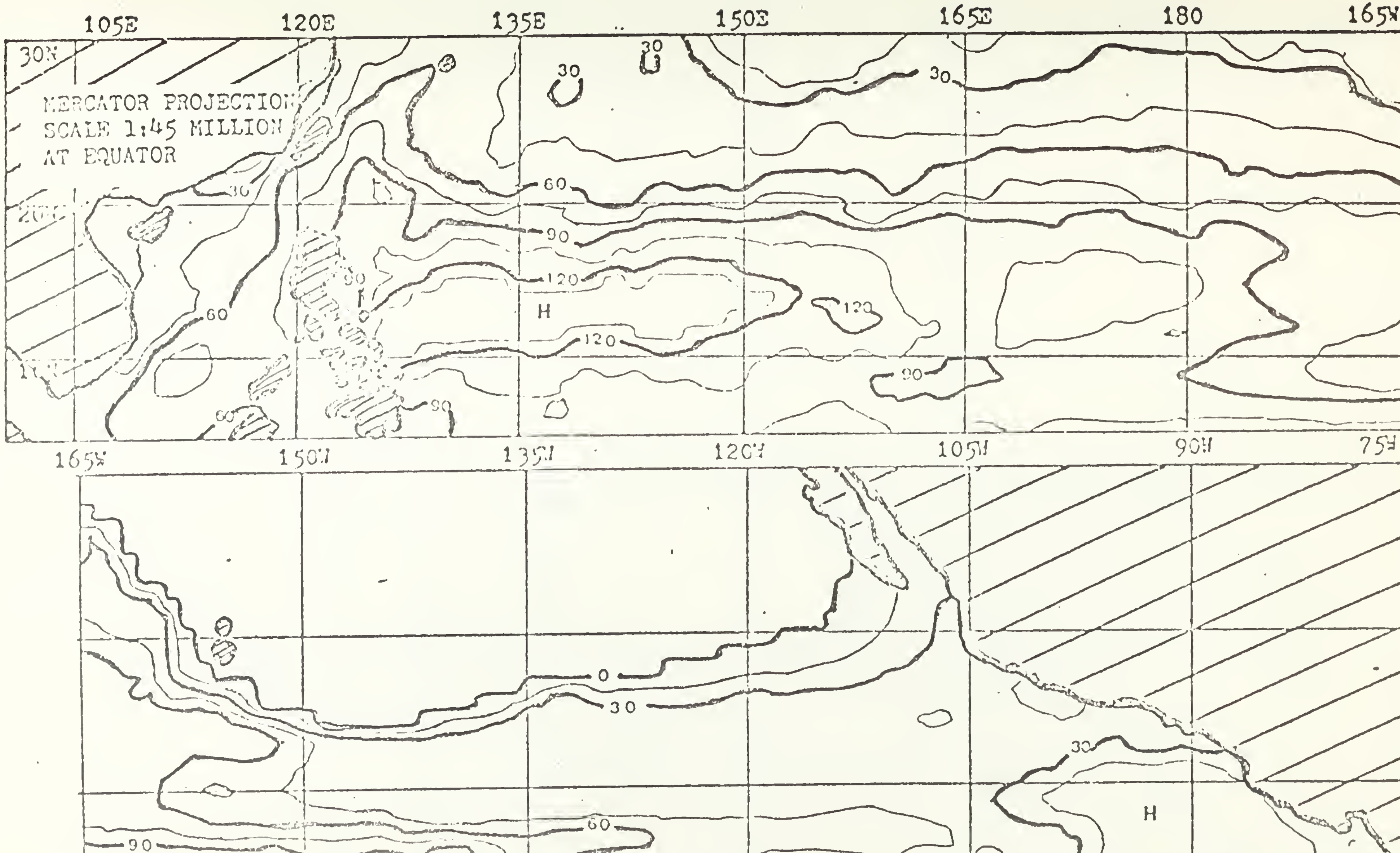


FIGURE (47): DECEMBER MEAN HURRICANE HEAT POTENTIAL, NORTH PACIFIC.

CONTOUR INTERVAL: 40
UNITS: $cal/cm^2 \times 10^{-2}$



(CONTOUR INTERVAL: 15 METERS)

FIGURE (48): AUGUST MEAN DEPTH OF 26C ISOTHERM, NORTH PACIFIC.

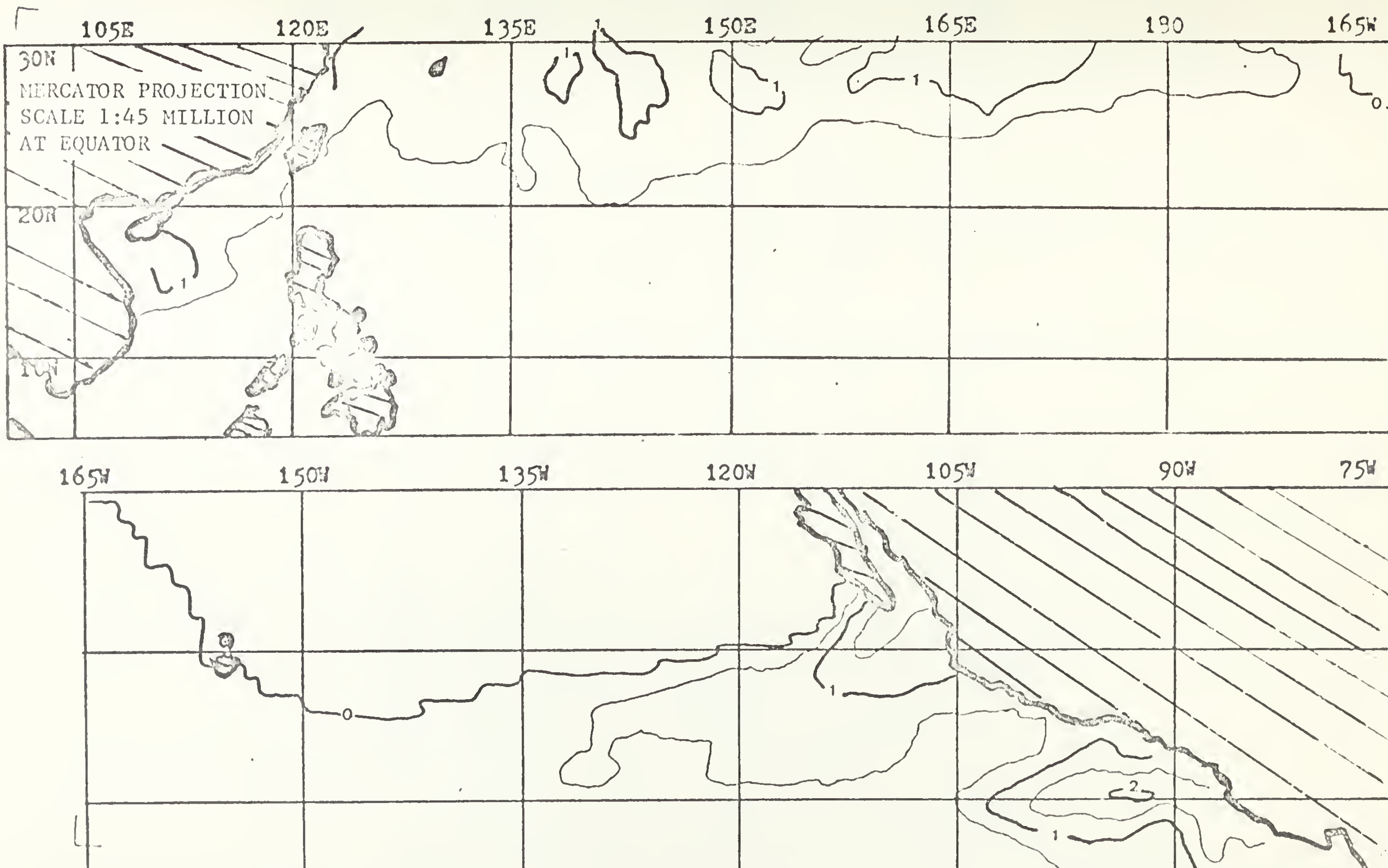


FIGURE (49): AUGUST MEAN SEA SURFACE TEMPERATURE MODIFICATION AFTER PASSAGE OF A HURRICANE, 06 HOUR EFFECT, NORTH PACIFIC. (CONTOUR INTERVAL: .5C)

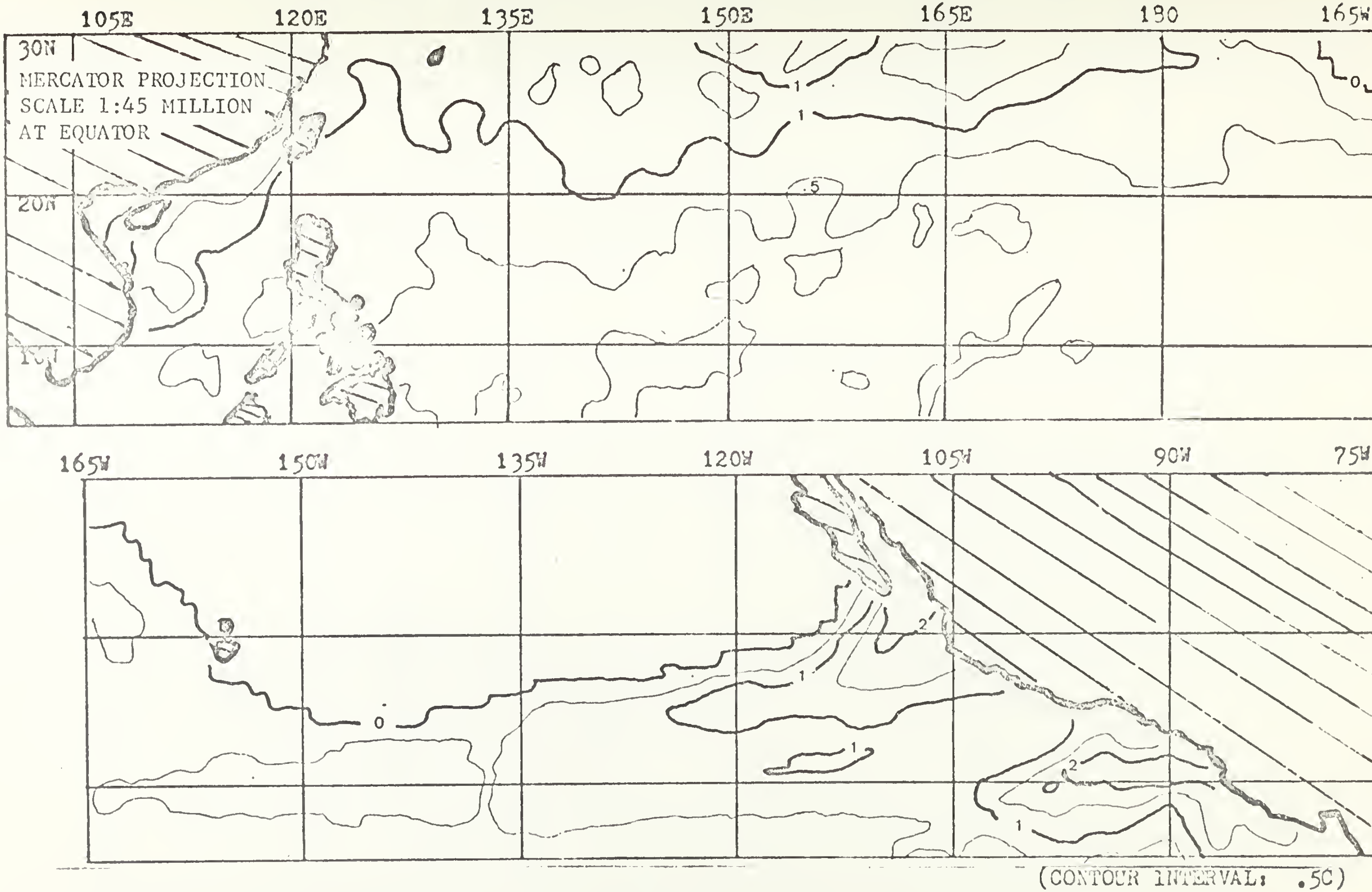
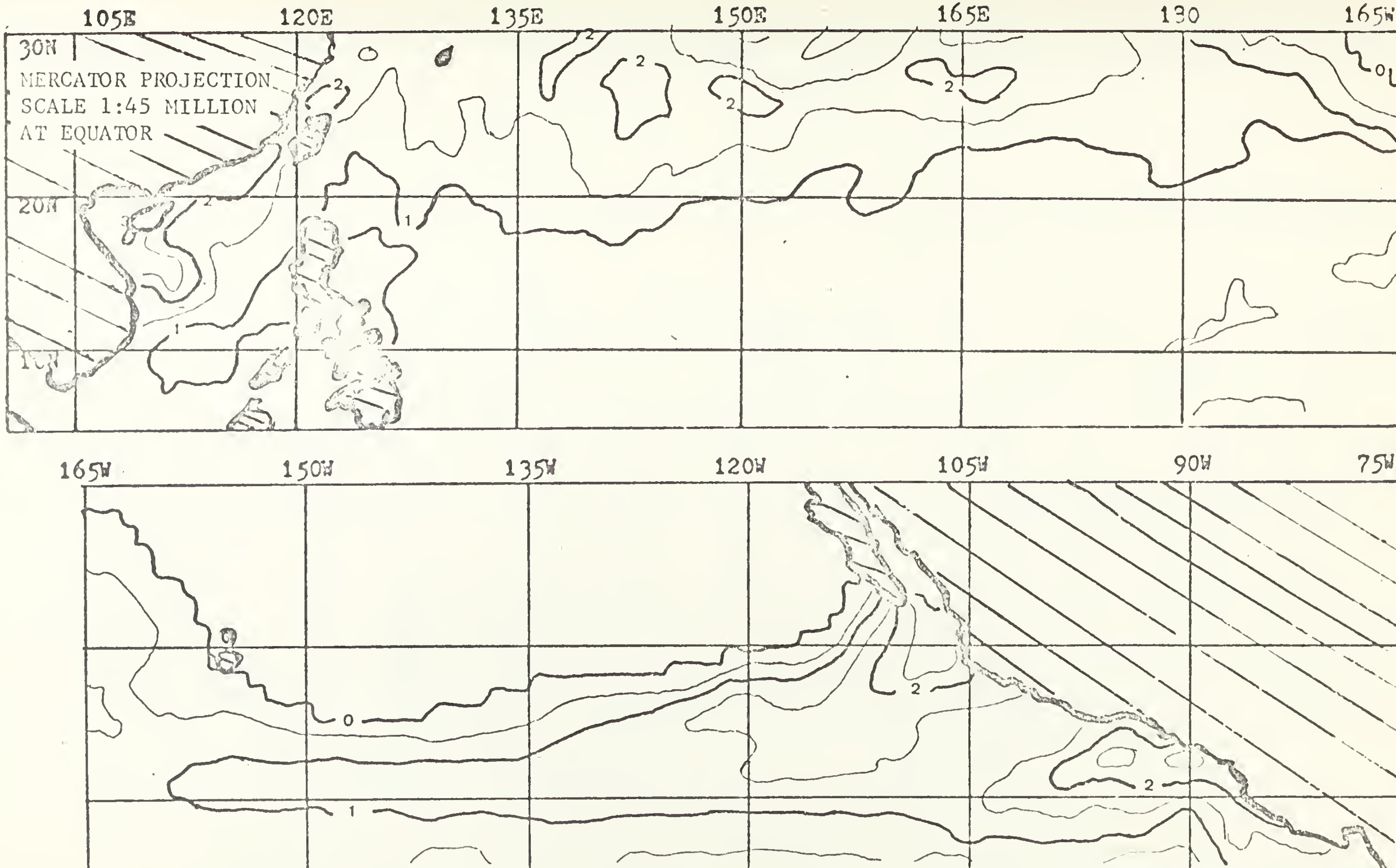


FIGURE (50): AUGUST MEAN SEA SURFACE TEMPERATURE MODIFICATION AFTER PASSAGE OF A HURRICANE, 12 HOUR EFFECT, NORTH PACIFIC.



(CONTOUR INTERVAL: .5C)

FIGURE (51): AUGUST MEAN SEA SURFACE TEMPERATURE MODIFICATION AFTER PASSAGE OF A HURRICANE, 24 HOUR EFFECT, NORTH PACIFIC.

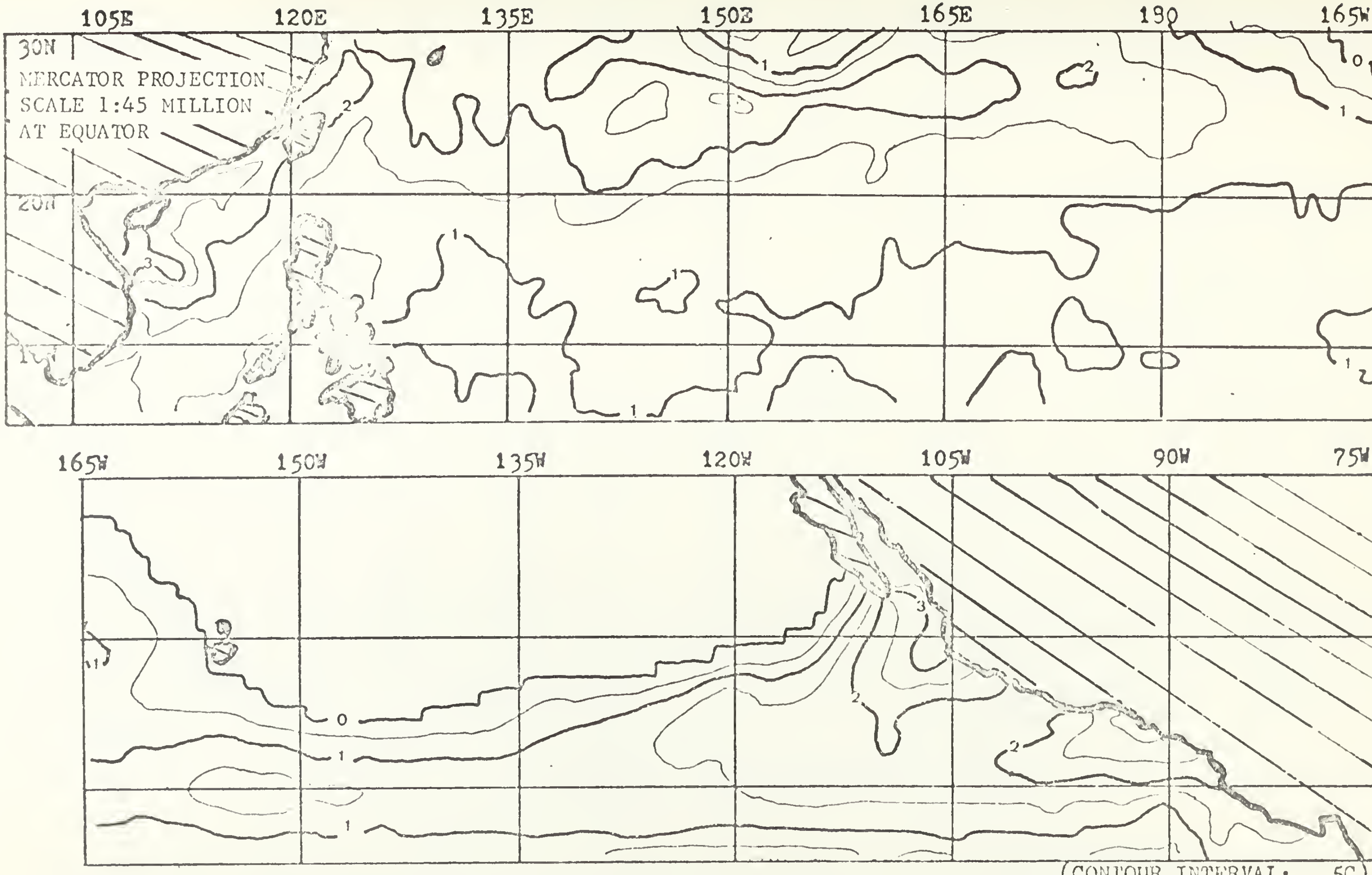
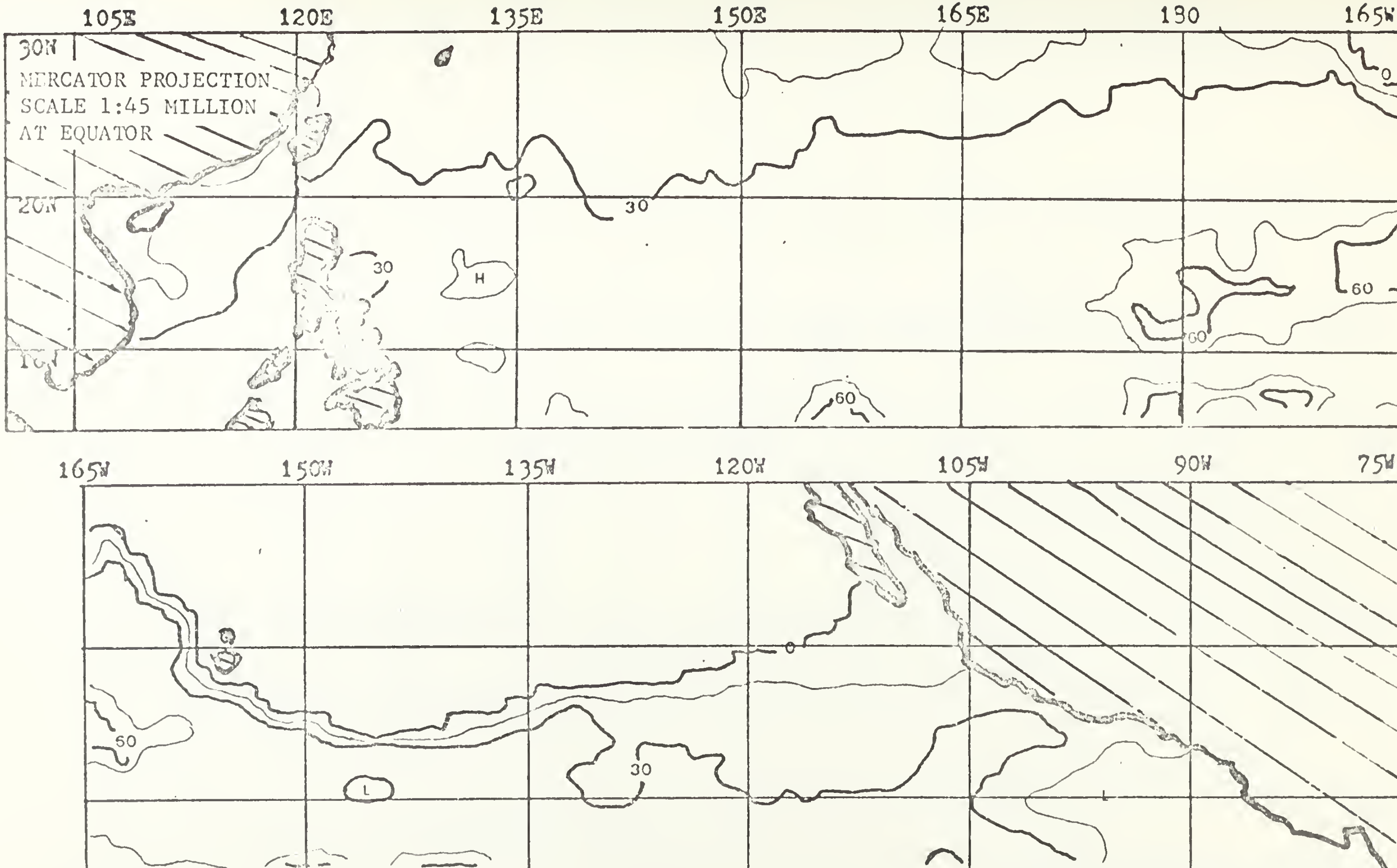
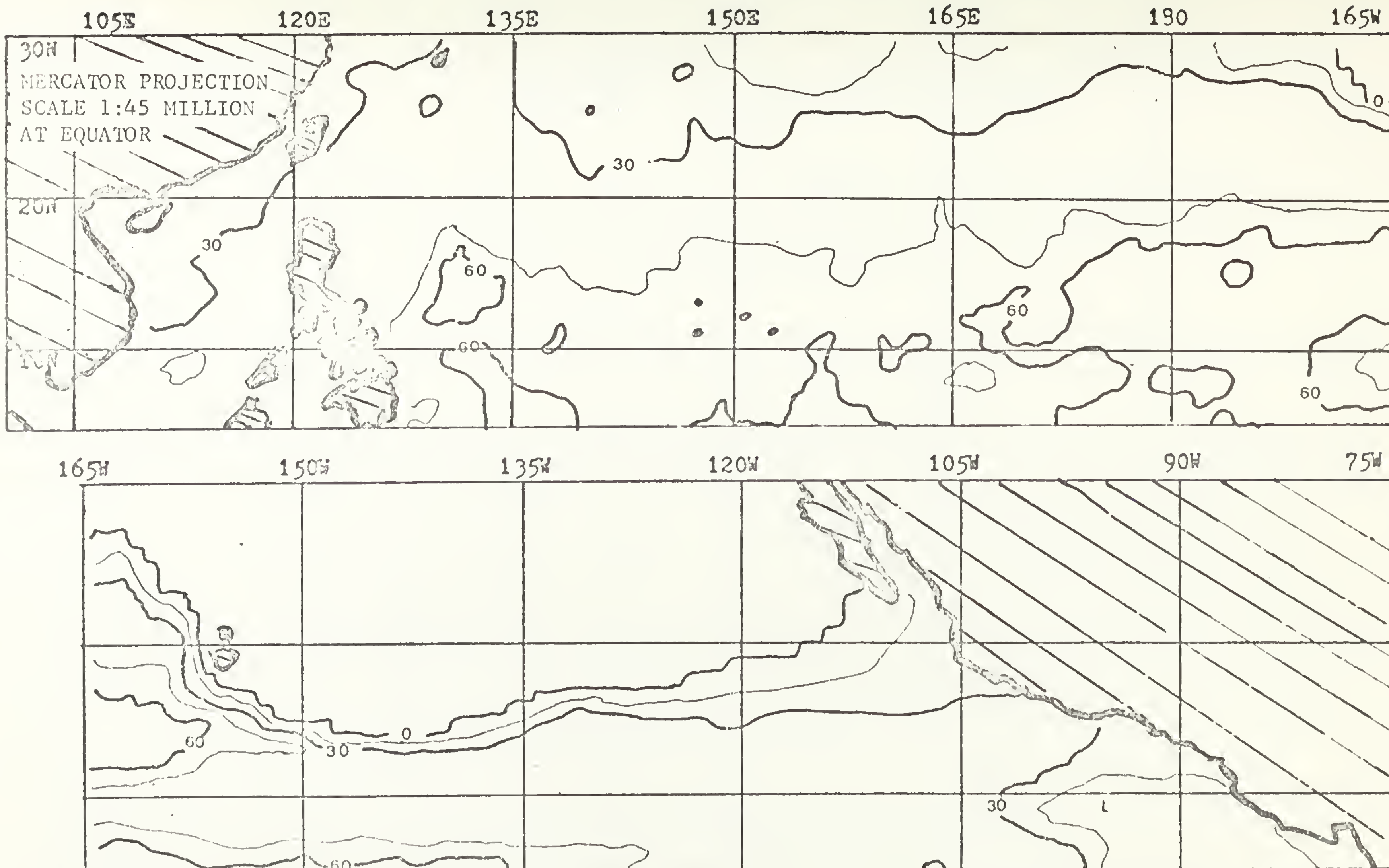


FIGURE (52): AUGUST MEAN SEA SURFACE TEMPERATURE MODIFICATION AFTER PASSAGE OF A HURRICANE, 36 HOUR EFFECT, NORTH PACIFIC.



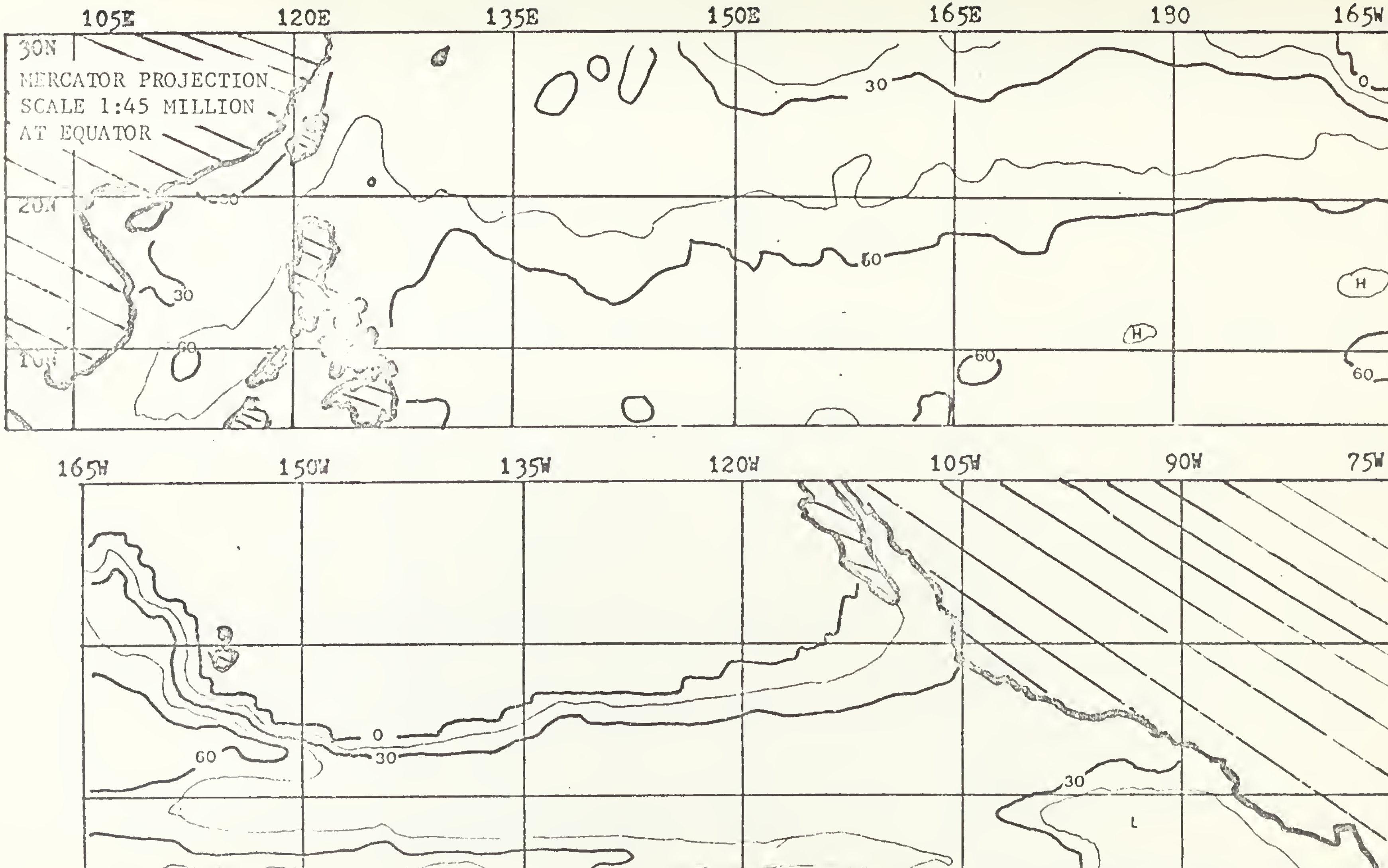
(CONTOUR INTERVAL: 15 METERS)

FIGURE (53): AUGUST MEAN CONVECTIVE LAYER DEPTH AFTER PASSAGE OF A HURRICANE, 06 HOUR EFFECT, NORTH PACIFIC.



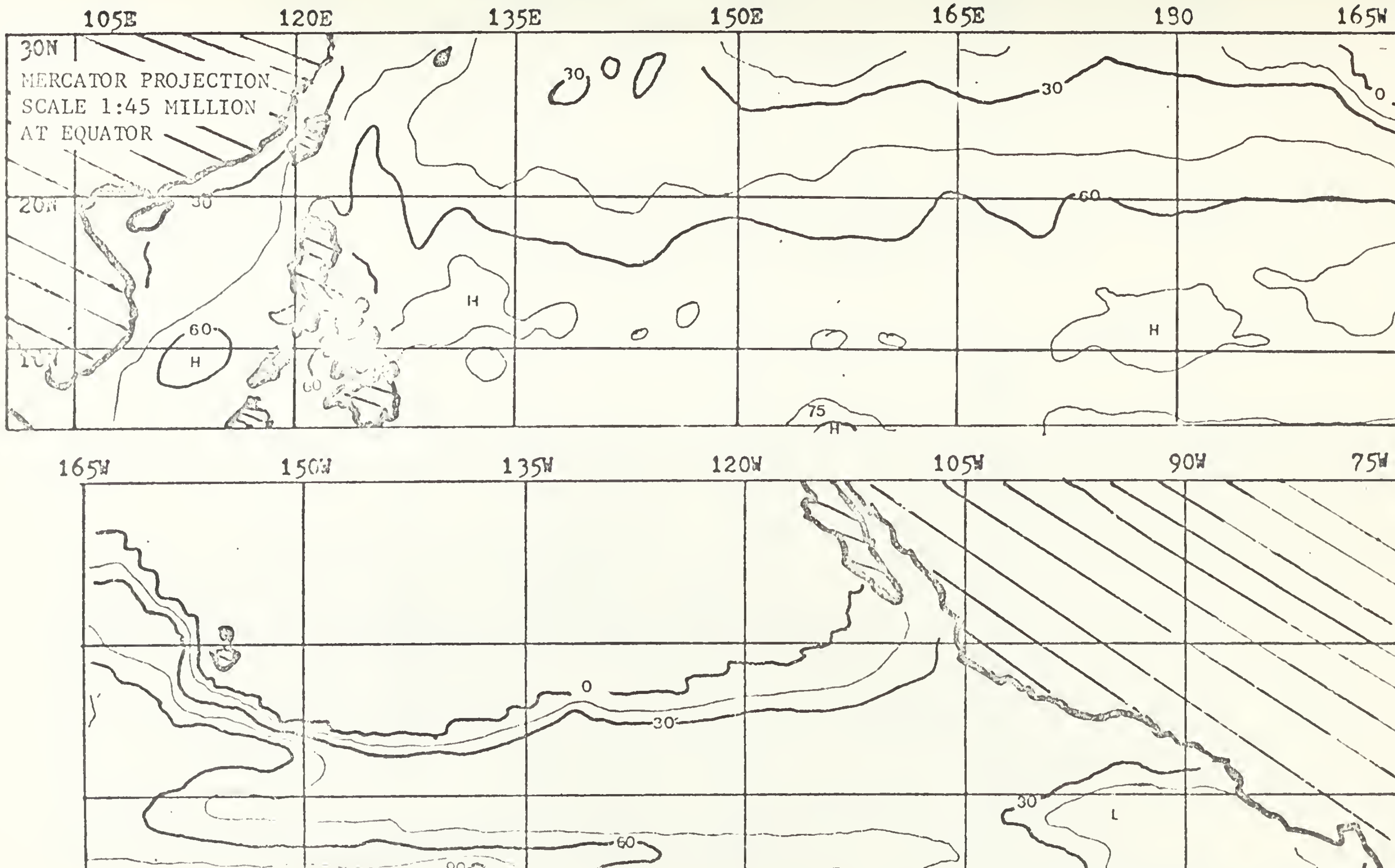
(CONTOUR INTERVAL: 15 METERS)

FIGURE (54): AUGUST MEAN CONVECTIVE LAYER DEPTH AFTER PASSAGE OF A HURRICANE, 12 HOUR EFFECT, NORTH PACIFIC.



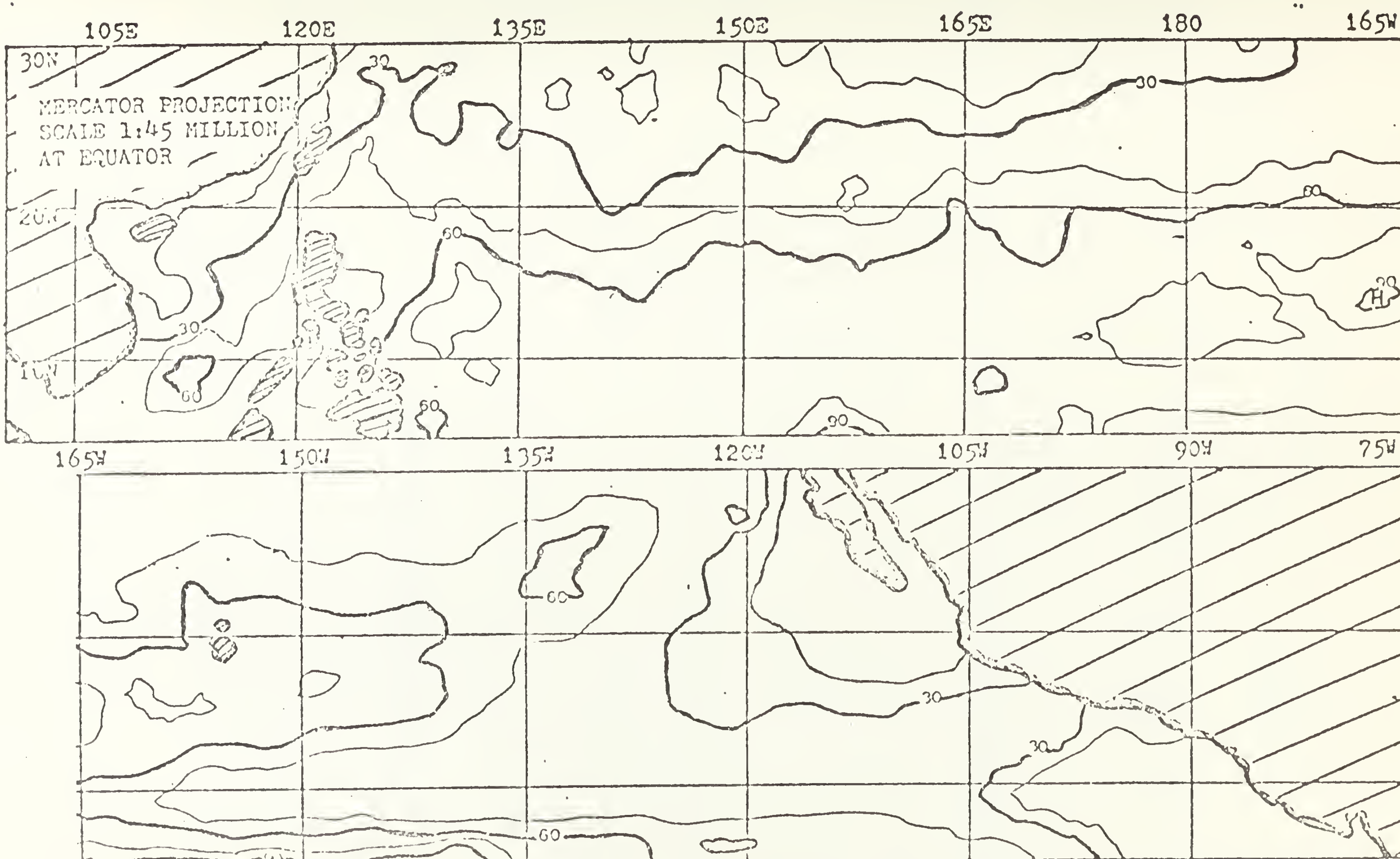
(CONTOUR INTERVAL: 15 METERS)

FIGURE (55): AUGUST MEAN CONVECTIVE LAYER DEPTH AFTER PASSAGE OF A HURRICANE, 24 HOUR EFFECT, NORTH PACIFIC.



(CONTOUR INTERVAL: 15 METERS)

FIGURE (56): AUGUST MEAN CONVECTIVE LAYER DEPTH AFTER PASSAGE OF A HURRICANE, 36 HOUR EFFECT, NORTH PACIFIC.



(CONTOUR INTERVAL: 15 METERS)

FIGURE (57): AUGUST MEAN LAYER DEPTH, NORTH PACIFIC

APPENDIX (A)

I. COMPUTER INPUT

A. Data stored on tapes HEFATL and HEFPAC were used as the basis for this study. The data were in the form of eighty character card images written in the format:

(I2, A1, I4, A1, I2, 12F4.1, 22X).

The following information was assigned to the above storage:

I2 - latitude (LAT.)

A1 - north or south (N. or S.)

I4 - longitude (LONG)

A1 - East or West (E. or W.)

I2 - level (LVL)

12F4.1 - sea temperature in degrees Farenheit for each level and month

22X - space filler

II. COMPUTER OUTPUT

A. Atlantic sea surface temperature modification Program (DLT) sample output.

LAT	LONG	LVL	sea surface temperature change (°C) per month											
09N	48W	Ø	3.0	2.0	0.0	1.0	4.0	3.0	3.0	5.0	8.0	6.0	2.0	2.0
09N	48W	1	6.0	2.0	0.0	4.0	6.0	5.0	5.0	8.0	11.0	9.0	4.0	4.0
09N	48W	2	10.0	2.0	0.0	4.0	7.0	8.0	9.0	13.0	16.0	14.0	9.0	9.0
09N	48W	3	10.0	2.0	0.0	4.0	7.0	8.0	12.0	17.0	21.0	19.0	13.0	13.0

For the above program, LVL Ø = 6 hour hurricane affect on the sea surface temperature. LVL1 = 12 hour affect. LVL 2 = 24 hour affect. LVL 3 = 36 hour affect. The months range in order from January through December. The temperatures are in degrees celsius times 10. The 1Ø multiple was necessary for use with the plot routine.

B. Atlantic Convective Layer Depth program (MXL) sample output:

LAT	LONG	LVL	Convective layer depth (meters) per month											
09N	48W	Ø	33.3	20.3	0.0	34.8	36.6	30.5	34.3	25.4	22.2	22.9	33.3	33.4
09N	48W	1	41.6	20.3	0.0	47.9	48.8	50.8	41.9	34.3	30.5	32.3	36.0	36.3
09N	48W	2	52.6	20.3	0.0	47.9	54.9	65.0	57.1	43.8	40.0	41.2	42.9	43.5
09N	48W	3	52.6	20.3	0.0	47.9	54.9	65.0	64.3	51.4	49.5	50.2	48.5	49.3

For the above program, LVL Ø = 6 hour hurricane affect on the thermostructure. LVL 1 = 12 hour affect. LVL 2 = 24 hour affect. LVL 3 = 36 hour affect.

C. Atlantic combined Sea Surface Temperature (°C), Heat Potential (cal/cm^2 times 10^{-2}) and Depth of the 26C Isotherm (meters) program (TQZ) sample output.

LAT	LONG	LVL	values of temp, heat, or depth per month											
09N	48W	Ø	27.1	26.2	26.0	26.4	26.8	26.9	27.4	28.2	28.5	28.1	27.8	27.6
09N	48W	1	35.1	1.7	0.0	14.9	23.2	33.6	60.8	81.8	73.7	65.0	72.2	66.9
09N	48W	2	51.7	17.4	0.0	47.9	55.4	67.1	66.7	61.0	55.4	53.1	53.5	53.2

For the above program, LVL Ø = sea surface temperature. LVL 1 = heat potential. LVL 2 = depth 26C isotherm.

III. DETAILED EXPLANATION OF PROGRAMS

A. MEAN MONTHLY HURRICANE HEAT POTENTIAL

The computer program was designed to allow for four cases:

Case(1): Sea Surface Temperature Less Than 26°C. This was computationally simple as the heat potential by definition was zero.

Case(2): Sea Surface Temperature Greater Than 26°C And Only One Level of Data Reported Due to Water Depth Less Than 30 Meters.

For a general solution, the water depth was set at 15 meters. The column of water was then partitioned into increments and heat computations were made for each segment above 26°C (referred to as excess temperature). The temperature profile was assumed decreasing linearly with depth to 26C at 15 meters. This was the most satisfactory means of providing an approximate value for heat potential. The situation arose infrequently and only when the one-degree quadrangle included or was contiguous with land, thus these values did not overly effect the field of computations.

Case(3): Sea Surface Temperature in Excess of 26°C and more than One Level of Data was Available.

This was the most common situation. There was the possibility of 4 to 5 difference levels being present since the data were available at 100 foot depth intervals. For instance, the first difference level consisted of the difference between sea surface temperature and the temperature at 30 meters (approximately 100 feet).

If the column was isothermal, the heat was computed simply by multiplying the excess temperature by the 3,000 cm depth. If not isothermal, the column was incremented assuming a linear variation between readings and heat computations were made for each segment using the average T of that segment down to the deeper level. The process then continued to the next levels or until case (4) arose.

Case (4): Temperature in Entire Column In Excess of 26°C. In this case, a linear assumption was again made between levels. The temperature difference between the last reported temperature at an even 30 meter level and 26°C was found. The projected depth to the 26°C isotherm was assumed to be 15 meters from the last level. This assumption provided a means to account for the temperature in excess of 26°C below the last reported level. Cases where this occurred were rare and the assumed heat values were small, thus the overall field was not effected.

B. DEPTH OF 26°C ISOTHERM

Determining the depth of the 26°C isotherm is important in that it gives and indication of the depth of the warm water.

The following cases apply:

Case (1): Sea Surface Temperature Less Than 26°C. The depth of the 26°C isotherm is defined as zero meters.

Case (2): Sea Surface Temperature Greater than 26°C and only One Level of Data Reported Due to Water Depth Less than 30 Meters.

The 26°C isotherm is assumed to be at 15 meters. This is a simple approximation to fit a general case. An exact solution could be obtained only if depths were recorded from charts and averaged over the 60 square miles of the area quadrangle being considered. This procedure would be too cumbersome and thus was not seriously considered.

Case(3): Sea Surface Temperature In Excess of 26°C and More Than One Level Of Data Was Available.

In this case, incremental values of depth are added until the depth of the 26C isotherm is reached.

Case (4): Temperature In Entire Column In Excess of 26°C.

In this case, the same procedures as in case (3) were followed and than the case (2) assumption is made.

C. TEMPERATURE LOSS FROM THE SEA SURFACE AFTER PASSAGE OF A SEVERE TROPICAL STORM.

Using the logic of Jensen (1970), this model simulated the withdrawal of heat from a given initial temperature profile by artificially lowering the sea surface temperature in 0.1C increments. The quantity of heat contained within each trapezoidal area produced between the old and new sea temperatures was calculated. A cumulative total was maintained and when the total reached 1000 cal/cm^2 the sea temperature simulated the passage of a severe tropical storm with a traverse time of six hours. When the total reached 2,000 cal/cm^2 , a traverse time of twelve hours was simulated. 4,000 cal/cm^2 corresponded to a twenty-four hour traverse time.

D. CONVECTIVE LAYER DEPTH

The convective layer depth is determined by adding the incremental depth values until the required calories/cm^2 for each storm duration is reached, or until all heat potential is removed from the ocean.

```
//HEFQ1149 JOB (1149,0521FT,OP12),'HEFFERNAN..BOX.H',TIME=7
// EXEC FORTCLGP,REGION=100K
//FORT.SYSIN DD *
C*****************************************************************
C     MEAN OCEAN HEAT POTENTIAL COMPUTATIONS FOR ATLANTIC
C     USING MEAN TEMPERATURE DATA COMPUTED BY M.K.ROBINSON
C     REGION BY ONE DEGREE SQUARES
C*****************************************************************
C     PURPOSE:
C               1.TO COMPUTE(Q),THE EXCESS OCEAN HEAT CONTENT
C                  OVER THAT CONTAINED IN 26C WATER.
C               2.TO COMPUTE(Z1),THE DEPTH OF THE 26C ISOTHRM
C               3.TO COMPUTE (A),THE SEA SFC TEMP IN DEGREE C
C     ARGUMENTS:
C               A-TEMPERATURE DEGREES C=(F-32)5/9
C               TEMP-TEMPERATURE DEGREES F.=9/5A+32
C               CP-SPECIFIC HEAT AT CONSTANT PRESSURE,
C                  TAKEN AS 1.0 CAL/GM-DEG
C               QI-INCREMENTAL HEAT CAL/CM2
C               RHO-DENSITY, TAKEN AS 1.0 GM/CM3
C               Z1-DEPTH OF INTERCEPT OF LINEAR TEMPERATURE
C                  APPROX WITH THE 26C DEGREE ISOTHERM
C               Q-CUMULATIVE HEAT CAL/CM2
C               ZI-SEQUENTIAL 30.48 METER DEPTH INTERVAL
C               HR()-NUMBER OF CALORIES IN HUNDREDS,TROPICAL
C                  STORM OBTAINED FROM THE COLUMN OF WATER
C                  FOR A FIXED PERIOD(6,12,24,36 HRS.).
C                  1000 CAL/CM2 PER FOUR HOUR PERIOD TAKEN
C                  AS CONSTANT.
C               TEMP2-CALCULATED SEA SFC TEMP AFTER PASSAGE
C                  OF TROPICAL STORM.
C               DIST-VARIABLE NUMBER OF INCREMENTS BETWEEN 30
C                  METER LEVELS.
C               XXX-INCREMENTAL TEMPERATURE CHANGE.
C               ZZZ-CONSTANT MULTIPLE FOR INCREASING NUMBER
C                  OF INCREMENTS.
C               Z2-INCREMENTAL DEPTH CHANGE
C     CALRY=AMOUNT OF HEAT HURRICANE  OBTAINED DURING TIME
C           INTERVAL HR( ).
C
C
C
C*****************************************************************
      DIMENSION A(12,6),TEMP(12,6),TEMP2(12),Q(12),KCNT(12),
     1DIST(12),QI(12),DIFF(12),Z1(12),X(12,6)
      INTEGER P,CLRY,Z111,TT1
      MM=0
      TTTT=26.03
      XXX=.050
      ZZZ=20.
      HR06=10.00
      HR12=20.00
      HR24=40.00
      HR36=60.00
      CALL REREAD
  204 READ(4,200,END=2) LAT,X1,LONG,IY,LVL,(TEMP(I,LVL+1),
     1I=1,12)
  200 FORMAT(I2,A1,I4,A1,I2,12F4.1,22X)
  203 SVLONG=LONG
  229 DO 201 J=2,6
C     MAX VALUE FOR PACIFIC IS 5 LEVELS
      READ(4,2001) LAT1,X2,LONG1,IY1,LVL1
 2001 FORMAT(I2,A1,I4,A1,I2,70X)
      IF(LONG1.NE.SVLONG) GO TO 205
      READ(99,200) LAT,X1,LONG,IY,LVL,(TEMP(I,LVL+1),I=1,12)
  201 CONTINUE
      ICNT=J
      GO TO 206
  205 ICNT=J-1
  206 DO 1 J=1,ICNT
      DO 1 I=1,12
      A(I,J)=(TEMP(I,J)-32.0)*(5./9.)
```

```
      X(I,J)=A(I,J)-26.0
    1 CONTINUE
      DO 3001 I=1,12
      CP=1.0
      RHO=1.0
      Q(I)=0.0
      Z1(I)=0.0
      TEMP2(I)=A(I,1)
      P=0
      NA=ICNT-1
      IF(X(I,1).LT.0.) GO TO 3001
      IF(NA.EQ.0) GO TO 699
      GO TO 700
C     THIS COASTAL REGION SUBPROGRAM IS FOR THE CASE WHEN
C     ONLY SEA SURFACE TEMP. IS REPORTED DUE TO SHALLOW
C     WATER.
  699 KCNT(I)=ZZZ*X(I,1)
      ZI=15.24
      JCNT=KCNT(I)
      DIST(I)=ZI/KCNT(I)
      DO 25 J=1,JCNT
      Z2=ZI/ZZZ
      Z1(I)=Z1(I)+Z2
      P=P+1
      TEMP2(I)=TEMP2(I)-XXX
      QI(I)=(RHO*CP*DIST(I))*(X(I,1)-XXX*P)
      IF(QI(I).LT.0.) GO TO 3001
      Q(I)=Q(I)+QI(I)
      IF(TEMP2(I).LT.TTTT) GO TO 3001
   25 CONTINUE
      GO TO 3001
C     THIS IS THE MAIN ANALYSIS PROGRAM FOR OCEAN DEPTHS
C     GREATER THAN 30 METERS.
  700 CONTINUE
      DO 13 K=1,NA
      IF(X(I,K).LE.0.) GO TO 3001
      IF(X(I,K+1).GT.X(I,K))DIFF(I)=X(I,K+1)-X(I,K)
      IF(X(I,K+1).GT.X(I,K))GO TO 1090
      DIFF(I)=X(I,K)-X(I,K+1)
 1090 CONTINUE
      KCNT(I)=ZZZ*DIFF(I)
      ZI=30.48
      IF(KCNT(I).EQ.0) GO TO 703
      GO TO 44
  703 CONTINUE
      QI(I)=ZI*X(I,K)
      Q(I)=Q(I)+QI(I)
      Z1(I)=Z1(I)+ZI
   17 CONTINUE
      GO TO 13
   44 CONTINUE
      JCNT=KCNT(I)
      DIST(I)=ZI/KCNT(I)
      P=0
      DO 19 L=1,JCNT
      P=P+1
      IF(X(I,K+1).GT.X(I,K)) TEMP2(I)=TEMP2(I)+XXX
      IF(X(I,K+1).GT.X(I,K)) GO TO 1091
      TEMP2(I)=TEMP2(I)-XXX
 1091 CONTINUE
      Z2=DIST(I)
      Z1(I)=Z1(I)+Z2
      IF(X(I,K+1).GT.X(I,K))QI(I)=DIST(I)*(X(I,K)+XXX*P)
      IF(X(I,K+1).GT.X(I,K))GO TO 1092
      QI(I)=(RHO*CP*DIST(I))*(X(I,K)-XXX*P)
 1092 CONTINUE
      IF(XXX*P.GT.DIFF(I)) GO TO 13
      Q(I)=Q(I)+QI(I)
      IF(TEMP2(I).LT.TTTT) GO TO 3001
   19 CONTINUE
   13 CONTINUE
      IF(X(I,NA+1).GT.0.) GO TO 701
```

```
      GO TO 3001
  701 KCNT(I)=ZZZ*X(I,NA+1)
      ZI=15.24
      JCNT=KCNT(I)
      DIST(I)=ZI/KCNT(I)
      P=0
      DO 24  J=1,JCNT
      P=P+1
      TEMP2(I)=TEMP2(I)-XXX
      Z2=DIST(I)
      Z1(I)=Z1(I)+Z2
      QI(I)=(RHO*CP*DIST(I))*(X(I,NA+1)-XXX*P)
      IF(QI(I).LT.0.) GO TO 3001
      Q(I)=Q(I)+QI(I)
      IF(TEMP2(I).LT.TTTT) GO TO 3001
   24 CONTINUE
 3001 CONTINUE
      TT1=0
      CLRY=1
      Z111=2
      MM=MM+1
      IF(MOD(MM,10).NE.0) GO TO 1100
      WRITE(6,900) LAT,X1,LONG,IY,TT1,(A(I,1),I=1,12)
      WRITE(6,900) LAT,X1,LONG,IY,CLRY,(Q(I),I=1,12)
      WRITE(6,900) LAT,X1,LONG,IY,Z111,(Z1(I),I=1,12)
 1100 CONTINUE
  900 FORMAT(1X,I2,A1,I4,A1,I2,12F5.1)
      WRITE(3,901) LAT,X1,LONG,IY,TT1,(A(I,1),I=1,12)
      WRITE(3,901) LAT,X1,LONG,IY,CLRY,(Q(I),I=1,12)
      WRITE(3,901) LAT,X1,LONG,IY,Z111,(Z1(I),I=1,12)
  901 FORMAT(1X,I2,A1,I4,A1,I2,12F5.1)
      IF(ICNT.EQ.6) GO TO 204
C     MAX VALUE FOR PACIFIC IS 5 LEVELS
      READ(99,200) LAT,X1,LONG,IY,LVL,(TEMP(I,LVL+1),I=1,12)
      GO TO 203
    2 CONTINUE
      STOP
      END

C     THIS JCL IS FOR READING A 7 TRACK TAPE, AND DUMPING
C     COMPUTED VALUES ONTO DATA CELL


//GO.FT04F001  DD UNIT=2400-1,LABEL=(1,NL),DISP=(OLD,KEEP),
// VOL=SER=HEFATL,DCB=(DEN=1,RECFM=F,BLKSIZE=80,TRTCH=ET)
//GO.FT03F001 DD DSNAME=S1149.TQZ,UNIT=2321,
// VOL=SER=CEL002,DISP=(NEW,KEEP),SPACE=(CYL,(40,1),RLSE),
// LABEL=EXPDT=72286,DCB=(RECFM=FB,BLKSIZE=2000,LRECL=80)
```

```
//HEFD1149 JOB (1149,0521FT,OP12),'HEFFERNAN..BOX.H',TIME=6
//   EXEC  FORTCLG
//FORT.SYSIN DD *

C*****************************************************************
C      MEAN OCEAN HEAT POTENTIAL COMPUTATIONS FOR ATLANTIC
C      USING MEAN TEMPERATURE DATA COMPUTED BY M.K.ROBINSON
C      REGION BY ONE DEGREE SQUARES
C*****************************************************************
C      PURPOSE:
C                 1.TO COMPUTE (DL--),THE CHANGE IN SEA SURFACE
C                    TEMP DUE TO PASSAGE OF A TROPICAL STORM.
C      ARGUMENTS:
C                 Q-CUMULATIVE HEAT CAL/CM2
C                 ZI-SEQUENTIAL 30.48 METER DEPTH INTERVAL
C                 HR()-NUMBER OF CALORIES IN HUNDREDS,TROPICAL
C                    STORM OBTAINED FROM THE COLUMN OF WATER
C                    FOR A FIXED PERIOD(6,12,24,36 HRS.).
C                    1000 CAL/CM2 PER FOUR HOUR PERIOD TAKEN
C                    AS CONSTANT.
C                 TEMP2-CALCULATED SEA SFC TEMP AFTER PASSAGE
C                    OF TROPICAL STORM.
C                 DIST-VARIABLE NUMBER OF INCREMENTS BETWEEN 30
C                    METER LEVELS.
C                 XXX-INCREMENTAL TEMPERATURE CHANGE.
C                 ZZZ-CONSTANT MULTIPLE FOR INCREASING NUMBER
C                    OF INCREMENTS.
C                 Z2-INCREMENTAL DEPTH CHANGE
C*****************************************************************

      DIMENSION A(12,6),TEMP(12,6),TEMP2(12),Q(12),KCNT(12),
     1DIST(12),QI(12),DIFF(12),Z1(12),X(12,6)
      DIMENSION DL06(12),DL12(12),DL24(12),DL36(12)
      INTEGER DT06,DT12,DT24,DT36,P
      MM=0
      TTTT=26.0
      XXX=.1
      ZZZ=10.
      HR06=10.00
      HR12=20.00
      HR24=40.00
      HR36=60.00
      CALL REREAD
  204 READ(4,200,END=2) LAT,X1,LONG,IY,LVL,(TEMP(I,LVL+1),
     1I=1,12)
  200 FORMAT(I2,A1,I4,A1,I2,12F4.1,22X)
  203 SVLONG=LONG
  229 DO 201 J=2,6
C     MAX VALUE FOR PACIFIC IS 5 LEVELS
      READ(4,2001) LAT1,X2,LONG1,IY1,LVL1
 2001 FORMAT(I2,A1,I4,A1,I2,70X)
      IF(LONG1.NE.SVLONG) GO TO 205
      READ(99,200) LAT,X1,LONG,IY,LVL,(TEMP(I,LVL+1),I=1,12)
  201 CONTINUE
      ICNT=J
      GO TO 206
  205 ICNT=J-1
  206 DO 1 J=1,ICNT
      DO 1 I=1,12
      A(I,J)=(TEMP(I,J)-32.0)*(5./9.)
      X(I,J)=A(I,J)-26.0
    1 CONTINUE
      DO 3001 I=1,12
      CP=1.0
      RHO=1.0
      Q(I)=0.0
      Z1(I)=0.0
      DL06(I)=0.
      DL12(I)=0.
      DL24(I)=0.
```

```
      DL36(I)=0.
      TEMP2(I)=A(I,1)
      P=0
      NA=ICNT-1
      IF(X(I,1).LE.0.) GO TO 3001
      IF(NA.EQ.0) GO TO 699
      GO TO 700

C     THIS COASTAL REGION SUBPROGRAM IS FOR THE CASE WHEN
C     ONLY SEA SURFACE TEMP. IS REPORTED DUE TO SHALLOW
C     WATER.

  699 KCNT(I)=ZZZ*X(I,1)
      IF(KCNT(I).LT.1) KCNT(I)=1
      ZI=15.24
      JCNT=KCNT(I)
      DIST(I)=ZI/KCNT(I)
      DO 25 J=1,JCNT
      Z2=ZI/ZZZ
      Z1(I)=Z1(I)+Z2
      P=P+1
      TEMP2(I)=TEMP2(I)-XXX
      QI(I)=(RHO*CP*Z1(I))*XXX
      Q(I)=Q(I)+QI(I)
      IF(TEMP2(I).LT.TTTT) GO TO 3001
      IF(Q(I).LE.HR06) DL06(I)=(A(I,1)-TEMP2(I))*10.
      IF(Q(I).LE.HR12) DL12(I)=(A(I,1)-TEMP2(I))*10.
      IF(Q(I).LE.HR24) DL24(I)=(A(I,1)-TEMP2(I))*10.
      IF(Q(I).LE.HR36) DL36(I)=(A(I,1)-TEMP2(I))*10.
      IF(Q(I).GT.HR36) GO TO 3001
   25 CONTINUE
      GO TO 3001

C     THIS IS THE MAIN ANALYSIS PROGRAM FOR OCEAN DEPTHS
C     GREATER THAN 30 METERS.

  700 CONTINUE
      DO 13 K=1,NA
      IF(X(I,K).LE.0.) GO TO 3001
      DIFF(I)=X(I,K)-X(I,K+1)
      KCNT(I)=ZZZ*DIFF(I)
      ZI=30.48
      IF(KCNT(I).EQ.0) GO TO 703
      GO TO 44

C     SUBROUTINE FOR CASE WHEN ISOTHERMAL CONDITIONS EXIST

  703 Z1(I)=Z1(I)+ZI
      QI(I)=Z1(I)*XXX
      Q(I)=Q(I)+QI(I)
      IF(Q(I).LE.HR06) DL06(I)=(A(I,1)-TEMP2(I))*10.
      IF(Q(I).LE.HR12) DL12(I)=(A(I,1)-TEMP2(I))*10.
      IF(Q(I).LE.HR24) DL24(I)=(A(I,1)-TEMP2(I))*10.
      IF(Q(I).LE.HR36) DL36(I)=(A(I,1)-TEMP2(I))*10.
      IF(Q(I).GT.HR36) GO TO 3001
      GO TO 13
   44 CONTINUE
      JCNT=KCNT(I)
      DIST(I)=ZI/KCNT(I)
      P=0
      DO 19 L=1,JCNT
      P=P+1
      TEMP2(I)=TEMP2(I)-XXX
      Z2=DIST(I)
      Z1(I)=Z1(I)+Z2
      QI(I)=(RHO*CP*Z1(I))*XXX
```

```
      IF(XXX*P.GT.DIFF(I)) GO TO 13
      Q(I)=Q(I)+QI(I)
      IF(TEMP2(I).LT.TTTT) GO TO 3001
C     DL VALUE IS MULTIPLE OF 10 TO FACILATATE PLOT PROGRAM
      IF(Q(I).LE.HR06) DL06(I)=(A(I,1)-TEMP2(I))*10.
      IF(Q(I).LE.HR12) DL12(I)=(A(I,1)-TEMP2(I))*10.
      IF(Q(I).LE.HR24) DL24(I)=(A(I,1)-TEMP2(I))*10.
      IF(Q(I).LE.HR36) DL36(I)=(A(I,1)-TEMP2(I))*10.
      IF(Q(I).GT.HR36) GO TO 3001
   19 CONTINUE
   13 CONTINUE
      IF(X(I,NA+1).GT.0.) GO TO 701
      GO TO 3001
  701 KCNT(I)=ZZZ*X(I,NA+1)
      ZI=15.24
      IF(KCNT(I).LT.1) KCNT(I)=1
      JCNT=KCNT(I)
      DIST(I)=ZI/KCNT(I)
      P=0
      DO 24 J=1,JCNT
      P=P+1
      TEMP2(I)=TEMP2(I)-XXX
      Z2=DIST(I)
      Z1(I)=Z1(I)+Z2
      QI(I)=(RHO*CP*Z1(I))*XXX
      Q(I)=Q(I)+QI(I)
      IF(TEMP2(I).LT.TTTT) GO TO 3001
      IF(Q(I).LE.HR06) DL06(I)=(A(I,1)-TEMP2(I))*10.
      IF(Q(I).LE.HR12) DL12(I)=(A(I,1)-TEMP2(I))*10.
      IF(Q(I).LE.HR24) DL24(I)=(A(I,1)-TEMP2(I))*10.
      IF(Q(I).LE.HR36) DL36(I)=(A(I,1)-TEMP2(I))*10.
      IF(Q(I).GT.HR36) GO TO 3001
   24 CONTINUE
 3001 CONTINUE
      DT06=0
      DT12=1
      DT24=2
      DT36=3
  900 FORMAT(1X,I2,A1,I4,A1,I2,12F5.1)
 1100 CONTINUE
      WRITE(3,901) LAT,X1,LONG,IY,DT06,(DL06(I),I=1,12)
      WRITE(3,901) LAT,X1,LONG,IY,DT12,(DL12(I),I=1,12)
      WRITE(3,901) LAT,X1,LONG,IY,DT24,(DL24(I),I=1,12)
      WRITE(3,901) LAT,X1,LONG,IY,DT36,(DL36(I),I=1,12)
  901 FORMAT(I2,A1,I4,A1,I2,12F5.1,10X)
      IF(ICNT.EQ.6) GO TO 204
C     MAX VALUE FOR PACIFIC IS 5 LEVELS
      READ(99,200) LAT,X1,LONG,IY,LVL,(TEMP(I,LVL+1),I=1,12)
      GO TO 203
    2 CONTINUE
      STOP
      END


C     THIS JCL IS FOR READING A 7 TRACK TAPE, AND DUMPING
C     COMPUTED VALUES ONTO DATA CELL
//GO.FT04F001  DD UNIT=2400-1,LABEL=(1,NL),DISP=(OLD,KEEP),
// VOL=SER=HEFATL,DCB=(DEN=1,RECFM=F,BLKSIZE=80,TRTCH=ET)
//GO.FT03F001 DD DSNAME=S1149.DLT,UNIT=2321,
// VOL=SER=CEL002,DISP=(NEW,KEEP),SPACE=(CYL,(40,1),RLSE),
// LABEL=EXPDT=72286,DCB=(RECFM=FB,BLKSIZE=2000,LRECL=80)
```

```
//HEF11149 JOB (1149,0521FT,OP12),'HEFFERNAN..BOX.H',TIME=6
//  EXEC  FORTCLG
//FORT.SYSIN DD *

C*****************************************************************
C       MEAN OCEAN HEAT POTENTIAL COMPUTATIONS FOR PACIFIC
C       USING MEAN TEMPERATURE DATA COMPUTED BY M.K.ROBINSON
C       REGION BY ONE DEGREE SQUARES
C*****************************************************************
C       PURPOSE:
C                 1.TO COMPUTE (Z1--),THE DEPTH OF THE MIXED
C                    LAYER EFFECTED BY TROPICAL STORM PASSAGE.
C                    STORM IN AREA FOR6,12,24,36HRS OR SEQUENCE
C                    OF FOUR STORMS CROSSING AREA.
C       ARGUMENTS:
C                 Q-CUMULATIVE HEAT CAL/CM2
C                 ZI-SEQUENTIAL 30.48 METER DEPTH INTERVAL
C                 HR()-NUMBER OF CALORIES IN HUNDREDS,TROPICAL
C                    STORM OBTAINED FROM THE COLUMN OF WATER
C                    FOR A FIXED PERIOD(6,12,24,36 HRS.).
C                    1000 CAL/CM2 PER FOUR HOUR PERIOD TAKEN
C                    AS CONSTANT.
C                 TEMP2-CALCULATED SEA SFC TEMP AFTER PASSAGE
C                    OF TROPICAL STORM.
C                 DIST-VARIABLE NUMBER OF INCREMENTS BETWEEN 30
C                    METER LEVELS.
C                 XXX-INCREMENTAL TEMPERATURE CHANGE.
C                 ZZZ-CONSTANT MULTIPLE FOR INCREASING NUMBER
C                    OF INCREMENTS.
C                 Z2-INCREMENTAL DEPTH CHANGE
C*****************************************************************

      DIMENSION A(12,6),TEMP(12,6),TEMP2(12),Q(12),KCNT(12),
     1DIST(12),QI(12),DIFF(12),Z1(12),X(12,6)
      DIMENSION Z106(12),Z112(12),Z124(12),Z136(12)
      INTEGER Z206,Z212,Z224,Z236,P
      MM=0
      TTTT=26.0
      XXX=.1
      ZZZ=10.
      HR06=10.00
      HR12=20.00
      HR24=40.00
      HR36=60.00
      CALL REREAD
  204 READ(4,200,END=2) LAT,X1,LONG,IY,LVL,(TEMP(I,LVL+1),
     1I=1,12)
  200 FORMAT(I2,A1,I4,A1,I2,12F4.1,78X)
  203 SVLONG=LONG
 229  DO 201 J=2,5
C     MAX VALUE FOR PACIFIC IS 5 LEVELS
      READ(4,2001) LAT1,X2,LONG1,IY1,LVL1
 2001 FORMAT(I2,A1,I4,A1,I2,126X)
      IF(LONG1.NE.SVLONG) GO TO 205
      READ(99,200) LAT,X1,LONG,IY,LVL,(TEMP(I,LVL+1),I=1,12)
  201 CONTINUE
      ICNT=J
      GO TO 206
  205 ICNT=J-1
  206 DO 1 J=1,ICNT
      DO 1 I=1,12
      A(I,J)=(TEMP(I,J)-32.0)*(5./9.)
      X(I,J)=A(I,J)-26.0
    1 CONTINUE
      DO 3001 I=1,12
      CP=1.0
      RHO=1.0
      Q(I)=0.0
      Z1(I)=0.0
      Z106(I)=0.
      Z112(I)=0.
      Z124(I)=0.
```

```
      Z136(I)=0.
      TEMP2(I)=A(I,1)
      P=0
      NA=ICNT-1
      IF(X(I,1).LE.0.) GO TO 3001
      IF(NA.EQ.0) GO TO 699
      GO TO 700

C     THIS COASTAL REGION SUBPROGRAM IS FOR THE CASE WHEN
C     ONLY SEA SURFACE TEMP. IS REPORTED DUE TO SHALLOW
C     WATER.

 699  KCNT(I)=ZZZ*X(I,1)
      IF(KCNT(I).LT.1) KCNT(I)=1
      ZI=15.24
      JCNT=KCNT(I)
      DIST(I)=ZI/KCNT(I)
      DO 25 J=1,JCNT
      Z2=ZI/ZZZ
      Z1(I)=Z1(I)+Z2
      P=P+1
      TEMP2(I)=TEMP2(I)-XXX
      QI(I)=(RHO*CP*Z1(I))*XXX
      Q(I)=Q(I)+QI(I)
      IF(TEMP2(I).LT.TTTT) GO TO 3001
      IF(Q(I).LE.HR06) Z106(I)=Z1(I)
      IF(Q(I).LE.HR12) Z112(I)=Z1(I)
      IF(Q(I).LE.HR24) Z124(I)=Z1(I)
      IF(Q(I).LE.HR36) Z136(I)=Z1(I)
      IF(Q(I).GT.HR36) GO TO 3001
   25 CONTINUE
      GO TO 3001

C     THIS IS THE MAIN ANALYSIS PROGRAM FOR OCEAN DEPTHS
C     GREATER THAN 30 METERS.

  700 CONTINUE
      DO 13 K=1,NA
      IF(X(I,K).LE.0.) GO TO 3001
      DIFF(I)=X(I,K)-X(I,K+1)
      KCNT(I)=ZZZ*DIFF(I)
      ZI=30.48
      IF(KCNT(I).EQ.0) GO TO 703
      GO TO 44

C     SUBROUTINE FOR CASE WHEN ISOTHERMAL CONDITIONS EXIST


  703 Z1(I)=Z1(I)+ZI
      QI(I)=Z1(I)*XXX
      Q(I)=Q(I)+QI(I)
      IF(Q(I).LE.HR06) Z106(I)=Z1(I)
      IF(Q(I).LE.HR12) Z112(I)=Z1(I)
      IF(Q(I).LE.HR24) Z124(I)=Z1(I)
      IF(Q(I).LE.HR36) Z136(I)=Z1(I)
      IF(Q(I).GT.HR36) GO TO 3001
      GO TO 13
   44 CONTINUE
      JCNT=KCNT(I)
      DIST(I)=ZI/KCNT(I)
      P=0
      DO 19 L=1,JCNT
      P=P+1
      TEMP2(I)=TEMP2(I)-XXX
      Z2=DIST(I)
      Z1(I)=Z1(I)+Z2
      QI(I)=(RHO*CP*Z1(I))*XXX
      IF(XXX*P.GT.DIFF(I)) GO TO 13
      Q(I)=Q(I)+QI(I)
```

```
      IF(TEMP2(I).LT.TTTT) GO TO 3001
      IF(Q(I).LE.HR06) Z106(I)=Z1(I)
      IF(Q(I).LE.HR12) Z112(I)=Z1(I)
      IF(Q(I).LE.HR24) Z124(I)=Z1(I)
      IF(Q(I).LE.HR36) Z136(I)=Z1(I)
      IF(Q(I).GT.HR36) GO TO 3001
   19 CONTINUE
   13 CONTINUE
      IF(X(I,NA+1).GT.0.) GO TO 701
      GO TO 3001
  701 KCNT(I)=ZZZ*X(I,NA+1)
      ZI=15.24
      IF(KCNT(I).LT.1) KCNT(I)=1
      JCNT=KCNT(I)
      DIST(I)=ZI/KCNT(I)
      P=0
      DO 24 J=1,JCNT
      P=P+1
      TEMP2(I)=TEMP2(I)-XXX
      Z2=DIST(I)
      Z1(I)=Z1(I)+Z2
      QI(I)=(RHO*CP*Z1(I))*XXX
      Q(I)=Q(I)+QI(I)
      IF(TEMP2(I).LT.TTTT) GO TO 3001
      IF(Q(I).LE.HR06) Z106(I)=Z1(I)
      IF(Q(I).LE.HR12) Z112(I)=Z1(I)
      IF(Q(I).LE.HR24) Z124(I)=Z1(I)
      IF(Q(I).LE.HR36) Z136(I)=Z1(I)
      IF(Q(I).GT.HR36) GO TO 3001
   24 CONTINUE
 3001 CONTINUE
      Z206=0
      Z212=1
      Z224=2
      Z236=3
 1100 CONTINUE
      WRITE(3,904) LAT,X1,LONG,IY,Z206,(Z106(I),I=1,12)
      WRITE(3,904) LAT,X1,LONG,IY,Z212,(Z112(I),I=1,12)
      WRITE(3,904) LAT,X1,LONG,IY,Z224,(Z124(I),I=1,12)
      WRITE(3,904) LAT,X1,LONG,IY,Z236,(Z136(I),I=1,12)
  904 FORMAT(I2,A1,I4,A1,I2,12F5.1,10X)
  901 FORMAT(1X,I2,A1,I4,A1,I2,12F5.1)
      IF(ICNT.EQ.5) GO TO 204
C     MAX VALUE FOR PACIFIC IS 5 LEVELS
      READ(99,200) LAT,X1,LONG,IY,LVL,(TEMP(I,LVL+1),I=1,12)
      GO TO 203
    2 CONTINUE
      STOP
      END

C     THIS JCL IS FOR READING A 7 TRACK TAPE, AND DUMPING
C     COMPUTED VALUES ONTO DATA CELL

//GO.FT04F001  DD UNIT=2400-1,LABEL=(1,NL),DISP=(OLD,KEEP),
// VOL=SER=HEFPAC,DCB=(DEN=1,RECFM=F,BLKSIZE=136,TRTCH=ET)
//GO.FT03F001 DD DSNAME=P1149.MXL,UNIT=2321,
// VOL=SER=CEL002,DISP=(NEW,KEEP),SPACE=(CYL,(40,1),RLSE),
// LABEL=EXPDT=72286,DCB=(RECFM=FB,BLKSIZE=2000,LRECL=80)
```

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13. ABSTRACT

Mean monthly ocean temperature data provided by Fleet Numerical Weather Central were used as a basis for computation of quantity defined as hurricane heat potential. Warm, deep centers with heat potential values in excess of 32,000 cal/cm^2 existed east of the Philippine Islands during the months of July through November. In the Western Atlantic warm, deep centers in excess of 24,000 cal/cm^2 existed south of Cuba during the months of August through October. Correlation studies were made between sea surface temperature and heat potential. A weak correlation was found, leading to the conclusion that sea surface temperature at least at times is a poor indicator of oceanic heat content. Computations were made to determine the effect of average heat loss during a severe tropical storm passage to the ocean thermal structure. Twenty-four hour average losses would cause the sea surface temperature to drop as much as three degrees celsius under certain initial conditions. The effects of heat loss on convective layer depth ranged from less than fifteen meters to over ninety meters.

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